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UH-1 TEST BED PROGRAM. VOLUME I.

Robert R. Butcher

Northrop Corporation

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# **USAAVSCOM TECHNICAL REPORT 72-19**

## **UH-1 TEST BED PROGRAM**

### **VOLUME I OF II**

AD752890

BY

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JUNE 1972

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Details of illustrations in  
this document may be better  
studied on microfiche

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# ABSTRACT

The UH-1H helicopter test bed program was accomplished at the U. S. Army Aeronautical Depot Maintenance Center (ARADMAC), Corpus Christi, Texas, during the period 4 October 1970 through 17 December 1971. The program objective was to determine the capability of state-of-the-art hardware to automatically accomplish inspection, diagnostic and prognostic maintenance functions on selected subsystems of the UH-1H helicopter. Northrop's hardware for the program is identified as a Maintenance Reporting System (MRS). Helicopter components, both serviceable and degraded, were run and monitored for malfunction discrimination by the MRS in ARADMAC test cells and in two UH-1H aircraft. Trending for prognosis was attempted while accumulating flight time on two additional UH-1H aircraft utilizing serviceable components. The test results demonstrated the objectives of the test bed program.

## FOREWORD

The UH-1 Helicopter Test Bed Program was conducted for the US Army Aviation Systems Command under a contract (No. DAAJ01-70-C-0828(P3L) with the Northrop Corporation Electronics Division. This program is a sub-element of the Department of the Army RD&E project (1F164204DC3201) to develop an Automatic Inspection, Diagnostic and Prognostic System (AIDAPS) for Army aircraft. The overall program is in response to a Qualitative Materiel Requirement for an AIDAPS which was approved by DA in October 1967.

### GOVERNMENT ASSESSMENT OF PHASE E VERIFICATION TEST

Volume II of this report documents the accomplishments under Phase E of the program. Phase E was a test of the Accuracy and Repeatability of the Northrop equipment. Page 2-4 of the report summarizes Northrop's diagnoses of the helicopter components (both serviceable or good and degraded or bad) which were implanted by the Government in the UH-1H aircraft. The table below lists the actual conditions of the test components implanted in the UH-1H aircraft monitored by Northrop:

<u>Conditions</u>	<u>Date</u>	<u>Engine</u>	<u>Transmission</u>	<u>90° Gear Box</u>	<u>42° Gear Box</u>
1	19 Nov 71	Bad	Bad	Bad	Bad*
2	24 Nov 71	Bad	Bad	Bad	Bad
3	3 Dec 71	Good	Bad	Good	Bad
4	7 Dec 71	Good	Bad	Good	Bad
5	9 Dec 71	Good	Good	Good	Bad
6	10 Dec 71	Good	Good	Good	Bad
7	14 Dec 71	Good	Good	Bad*	Good
8	16 Dec 71	Good	Good	Bad	Good

\*The component conditions noted with an asterick (above) were revealed to the Contractor prior to his final analysis and are not included in the percentage scores shown below. The remaining component conditions had not previously been identified to the Contractor.

Northrop was required by contract to determine "good" components from "bad" components as implanted in the aircraft. They chose to indicate that engine conditions 2 thru 8 were "Bad" or "degraded." Engine condition 2 was so marginal as to constitute an extreme hazard to safe flight. Engine condition 3 thru 8 was the same engine in each case. This engine was carefully inspected and assembled prior to the test and was disassembled and carefully inspected after the test. There was nothing found during the pre-test or post-test inspection to indicate that the engine was degraded. It is therefore concluded from Phase E that Northrop's diagnostic equipment did not demonstrate desired capability to differentiate between "good" and "bad" engines. The overall diagnosis of the transmission, 90° gear box and 42° gear box was 86% accurate.

Although the Northrop equipment did achieve objectives of the Test Bed Program to demonstrate state-of-the-art capability, the foregoing results are not satisfactory for immediate hardware implementation.

The efforts expended by the Northrop Corporation and assigned personnel were very commendable. The above efforts and the knowledge accumulated will be used in subsequent steps during development of AIDAPS.

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## ABBREVIATIONS

A/C	Aircraft
ACC	Accessory
ACCEL	Accelerometer
AIDAPS	Automatic Inspection, Diagnostic and Prognostic System
AMP	Amplifier
ARADMAC	Army Aeronautical Depot Maintenance
AN/ASH-23	Sound Recorder Set
ATTN	Attenuator
AVG	Average
AVSCOM	Aircraft Systems Command
AZ	Azimuth
BHC	Bell Helicopter Company
Brg, BONG	Bombing
CALC	Calculator
CDP	Control Display Panel
CIPR	Control Instrument Panel Reference
COMPR	Compressor
CPR	Circuit Power Ratio
Curr	Current
D	Distance
DEGEL	De-icing
$\delta$	$P_{amb}$ Ambient Pressure
$\Delta$	Difference
$\Delta T$	Difference Temperature
DET	Detector
Diff.	Differential
DISPLT	Displacement
DRU	Data Recovery Unit
DS	Direct Support
DX	Direct Exchange Procedure
EGT	Exhaust Gas Temperature
EMER	Emergency
ENG	Engine
EU	Electronics Unit (Component of MRS)

## ABBREVIATIONS (Continued)

FM	Frequency Modulation
FLT	Flight
FOD	Foreign Object Damage
FREQ	Frequency
FSS	Functional System Simulator
GB	Gear Box
Gen	Generator
GND	Ground
GOV	Governor
GS	General Support
HP	Horsepower
HYD	Hydraulic
Hz	Hertz (frequency unit)
IFR	Instrument Flight Rule
IGV	Inlet Guide Vane
IND	Indicated, Indicator
IRIG	Inter-range Instrumentation Group
ISRS	Integrated Status Reporting System
J BOX	Junction Box
K Hz	1000 Hertz (also KC)
KTS	Knots
LAT	Lateral
LOP	Logistics Offensive Program
LRU	Line Replaceable Unit
LSB	Least Significant Bit
LVDT	Linear Variable Differential Transformer
MAC	Maintenance Allocation Chart
MPRV	Main Pressure Relief Valve
MPX	Multiplex
MRP	Military Rated Power
MRS	Maintenance Reporting System
MS+	Maintenance Support Positive
MV	Millivolt
MWO	Modification Work Orders

## ABBREVIATIONS (Continued)

NED	Northrop Electronics Division
NOZ	Nozzle
NRP	Normal Rated Power
$N_1$	Compressor Revolutions per Minute (in percent of nominal)
$N_2$	Power Turbine Revolutions per Minute (in percent of nominal)
nII	Power Turbine Speed ( $N_2$ )
Norm	Normal
OAT	Outside Air Temperature
ORG	Organizational
OSC	Oscillator
$P_{amb}$	Ambient Air Pressure
PLP	Power Level Position
P/N	Part Number
PFH	Pounds per Hour
Press.	Pressure
PSD	Power Spectral Density
Q	Torque Pressure
QMR	Qualitative Material Requirement
REG	Register
REV	Revolution
RMS	Root Mean Square
RSS	Root of Sum of Squares
SHP	Shaft Horse Power
SOP	Standard Operating Procedure
STBY	Stand-by
TAERS	The Army Equipment Reporting System
$T_{amb}$	Ambient Temperature
TAMMS	The Army Maintenance Management System
TBO	Time Between Overhaul
TBD	To Be Determined
$\theta$	$(OAT + 400)/519$
TM	Technical Manual
T/R	Transmission

## ABBREVIATIONS (Concluded)

Ver.	Vertical
Vib.	Vibration
$W_F$	Fuel Flow
Wht	White
V	Volt
VSA	Vibration System Analyzer, Vibration Spectrum Analyzer
XDCR	Transducer
XMSN	Transmission

## **SECTION 1**

## 1.0 SUMMARY AND INTRODUCTION

This section presents highlights, including accomplishments, of the UH-1H Helicopter Test Bed Program for an Automatic Inspection, Diagnostic and Prognostic System which was conducted at the U. S. Army Aeronautical Depot Maintenance Center (ARADMAC), Corpus Christi, Texas from 4 October 1970 through 13 September 1971. Readers desiring more detailed information on selected phases of the test bed program are referred to subsequent sections of this report.

The test bed program was accomplished by the Electronics Division of Northrop Corporation, Palos Verdes Peninsula, California for the U. S. Army Aviation Systems Command (AVSCOM). The objective of the program was to determine the capability of off-the-shelf hardware to detect UH-1H helicopter malfunctions, isolate faulty components, and by the use of trending techniques, predict the life remaining in serviceable components.

### 1.1 MAINTENANCE REPORTING SYSTEM

Northrop's equipment for the program is identified as a Maintenance Reporting System (MRS). It is an adaptation of Northrop's complete flight safety/maintenance system (Integrated Status Reporting System) successfully applied to the F-104 aircraft for the West German Air Force, and smaller systems applied to numerous helicopters over the past several years. Both these programs cover a decade of development and testing.

The design philosophy for the MRS was to incorporate the experience from the previous programs, and tailor a system keyed to the critical weight, volume, cost, maintenance significant components, and Army operational and environmental restraints associated with the UH-1H helicopter. In accommodating these considerations, the MRS possesses the following capability and flexibility.

1. Inflight distillation and computation of pertinent maintenance data
2. Recovery of recorded data subsequent to a mission in directly usable format at plane-side
3. Accomplishment of MRS operation and maintenance using minimum skill levels

4. Simultaneous recording of diagnostic events, quantitative data for trending and prognostic analysis, and maintenance related observations by the flight crew.
5. Maximum utilization of existing aircraft signal sources
6. All maintenance events correlated to time (occurrence and length)

The results of the design philosophy outlined above was an MRS Electronic Unit (EU) that measures 11"x7"x6" and weighs 11 pounds. The EU is mated with a Continuous Inflight Performance Recorder (CIPR) which measures 4.3 inches in diameter, 5.8 inches in length, and weighs 3.5 pounds (see Figure 1-1). The CIPR is a type classified item in the Army inventory as part of the Army Flight Safety System. The EU and CIPR are connected by cabling to sensors located on selected UH-1H components. Weight of the cabling and sensors totals approximately 36 pounds. A ground piece of equipment called a Data Recovery Unit (DRU) completes the MRS system. The DRU used for the test bed program is identical to the unit used for the programs previously mentioned, and although several years old, is portable and usable at the flight line. The DRU extracts information from the CIPR magnetic tape and produces, at plane-side, a hard copy record of the aircraft status.

The selection of parameters for monitoring by MRS entailed an exhaustive analysis of UH-1H maintenance problems. The problems were defined using Army technical manuals, down to the individual Line Replacement Unit (LRU) authorized for replacement by the Maintenance Allocation Chart primarily at the organizational level of maintenance. This approach will facilitate the implementation of the Department of the Army Logistics Offensive Program including Maintenance Support Positive and Direct Exchange procedures. Analysis of maintenance problems indicated the bulk of UH-1H maintenance was expended on the engine, rotors, main transmission, drive train, and 42 and 90 degree gear boxes. The sensor selection effort for MRS was concentrated in these major component areas. Existing aircraft signals were used to the maximum extent possible, thus requiring the addition of only 38 new sensors.

In describing the MRS from a system viewpoint, the approach toward monitoring of the major UH-1H subsystems includes the mechanization of techniques associated with vibration, temperature, pressure and fuel flow.

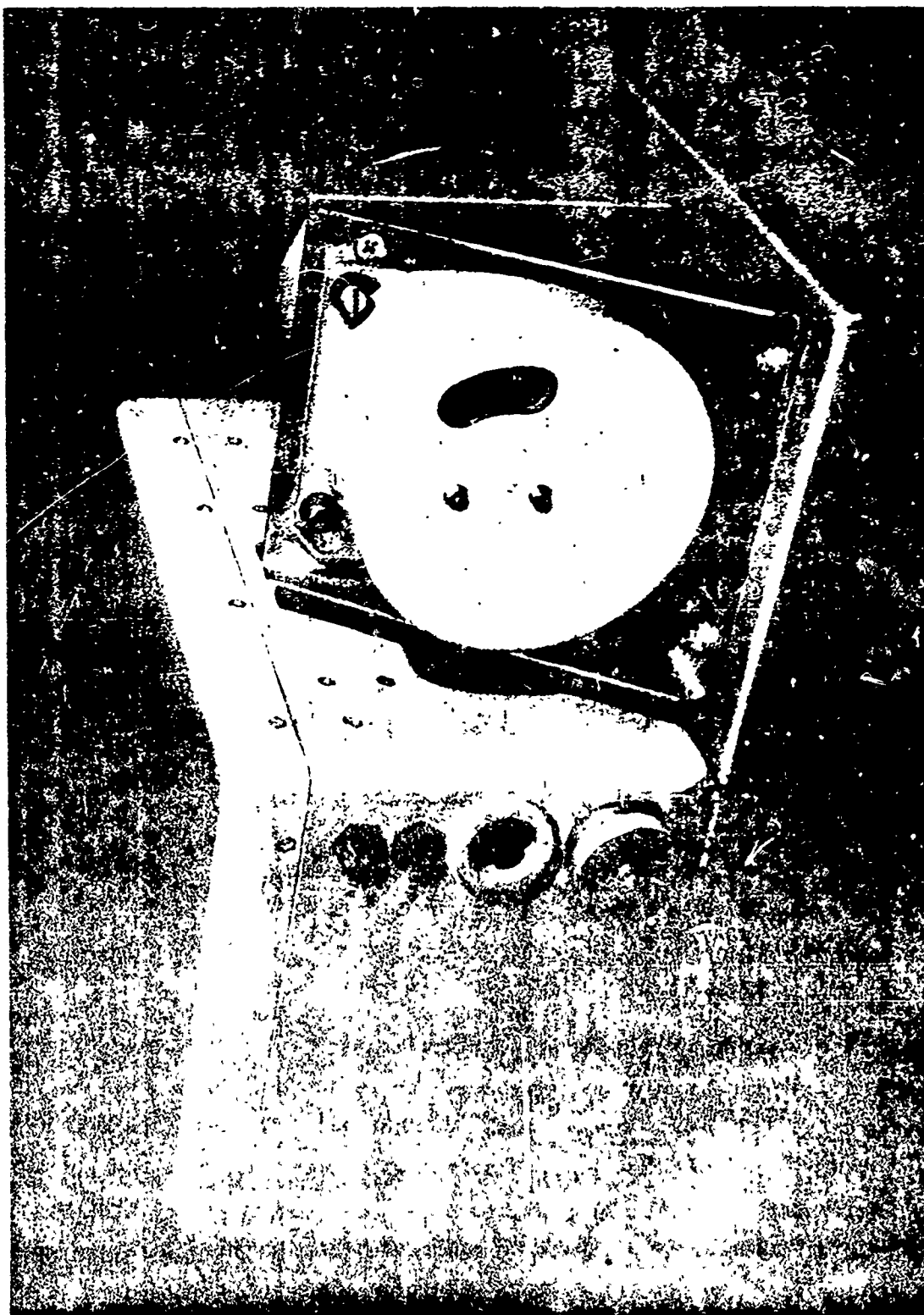


FIGURE 1-1 MRS SYSTEM

The basic maintenance system operation starts with the monitoring of signals and sensors. After each input signal has been conditioned into a usable form, it is then gated, summed, and compared with established norms. Signals that match a normal parameter value would be ignored and no unnecessary data recorded. Out-of-limit parameter values are observed by the MRS and reported as maintenance codes. The system provides three levels of degradation or exceedance, as illustrated in Figure 2-1. This information is stored on the maintenance recorder along with the time of occurrence and length of time the condition remained out of limits. Since the MRS monitors all parameters continuously, the observation of parameter exceedance is assured, thus eliminating one of the major limitations of human monitors or ground-based systems. Conversely as previously mentioned, the MRS does not record any data if the parameters monitored remain within normal limits. In addition, the MRS has visual indicators on the front of the Electronics Unit which display cumulative engine over-temperature, over-speed, and running time, as well as a GO/NO-GO flag reflecting items critical to aircraft system health, an MRS failure flag, and a NO-GO reset button.

#### 1.2 TEST BED PROGRAM CONDUCT

The test bed program was phased as follows

1. Phase A - Adaptation and Installation Engineering
2. Phase B - Test Cell Operation
3. Phase C - Preparation for the Flight Test
4. Phase D - Flight Test

Phase A activity encompassed engineering study and analysis which permitted finalization of parameter and signal source selection. Masses of data from the Northrop data bank, Army sources, and the prime UH-1H airframe and engine manufacturer were reviewed. Coordination with combat experienced operational and logistically oriented Army aviators was effected to ensure real world inputs to the test bed program. Visits were made to ARADMAC where detailed measurements/schematics were made of the engine, main transmission, 42/90 degree gear box test cells, and UH-1H aircraft. These measurements/schematics permitted prefabrication of MRS cabling, and selection of test cell points where

sensors could be emplaced. In addition, brackets and mounting fixtures were designed and manufactured. The total package of installation plans and drawings were then submitted to AVSCOM for approval. Upon approval, the total system was assembled, calibrated, and bench tested.

During Phase B, the engine, main transmission, and 42/90 degree gear box test cells were instrumented. Calibration checks were made of the MRS and the test cell equipment to ensure their compatibility. Baseline data on serviceable engines, transmissions and gear boxes were secured with the objective of establishing normal signature data. Subsequently, discrepant parts were implanted in these components; i.e., bad compressors, quill bearings, etc., and a series of abnormal signature data runs were accomplished. The same major components, plus the discrepant parts, were set aside for utilization during the flight test phase.

Phase C was devoted to installation of the MRS on two UH-1H aircraft. The initial MRS installation was completed in four days using three personnel. Ground run-ups and hover checks were accomplished to verify the compatibility of the aircraft and the MRS. After completion of these checks, flight tests were accomplished on both aircraft, and they were released for the flight phase.

Phase D was the culmination of all the detailed planning and engineering effort. The UH-1H helicopters were used in two modes. One helicopter was used as a trend aircraft and flown on normal Army missions without implanting any defective components. The other helicopter was flown with the same implanted discrepant parts used in the test cells. A total of 236 hours was accumulated on the trend aircraft, and 86 hours on the one with discrepant parts. Upon the completion of Phase D, a verification test was conducted. This test provided for the implanting of discrepant parts in the UH-1H without the knowledge of the contractor. A summary of the results is presented below with additional details presented in Section 8.0.

### 1.3 CONCLUSIONS AND RESULTS

The MRS successfully accomplished the overall test bed objectives of detecting UH-1H malfunctions and fault isolating defective components. However, the duration and conduct of the flight test effort provided

insufficient data from which prognostication of remaining component life could be made. As demonstrated in the verification portion of Phase D, the MRS correctly identified a substantial number of the implanted discrepant parts. This becomes even more significant when it is realized that the majority of the parts selected were only marginally discrepant. This is emphasized by the fact that only a small portion of all discrepant parts operated in the ARADMAC test cells using production test equipment exceeded cell instrumentation limits.

The areas of maximum benefit from the MRS in effective diagnoses of component condition are obtained from the vibration spectrum analyzer and the engine health calculator. The data derived from accelerometers monitoring the compressor, combustion and power turbine sections of the engine, as well as that obtained from the main transmission, 42 and 90 degree gear boxes, illustrated that bad bearings, FOD, and engine drive shaft maintenance problems can be identified and isolated to major components. Engine performance was assessed with not only vibration data, but also from gas flow analysis and the engine calculator. Gas flow analysis of engines with discrepant compressors indicated a reduction in compressor pressure ratios, increased EGT, and a loss in computed shaft horsepower. The engine calculator provides an airborne mechanization of selected engine parameters/equations including compressor pressure ratio, EGT, and fuel flow, normalized against  $N_1$ , ambient air temperature and pressure. A comparison of gas flow analysis and engine calculator outputs of engines with degraded compressors, where marked degradation/increases in CPR and EGT were obvious, continually showed correlation between degradation/increases in CPR and EGT from the gas flow, and changes in the engine calculator parameter values.

In conclusion, the UH-1H test bed program conclusively proved that the MRS is capable of detecting helicopter malfunctions and fault isolating discrepant LRU's, thereby unquestionably illustrating the potential cost savings inherent in such equipment application and the desirability of immediately pursuing a UH-1/AH-1 development program.

## **SECTION 2**

## 2.6 PROGRAM APPROACH

Northrop's approach to the UH-1H Test Bed Program was selected with consideration given to the stated Army objective for exploratory development projects; that is, providing solutions to military hardware problem areas, and to the unique operational and logistical problems encountered by the Army on the battlefield.

These considerations introduced many of the procedures and techniques into a test bed program, normally addressed only in a concurrent Engineering/Service Test of Army equipment. The Maintenance Reporting System is a simple system, which was substantiated by the fact that the MRS was operated numerous times during the program by Army UH-1H crew chiefs with minimum skill levels. Planning for data recovery was tailored so as to support Army operational and logistical requirements, thus permitting data recovery in a usable format within three minutes after landing, at planeside. Additional considerations keyed to exploratory development objectives and Army operational and logistical procedures are presented below.

### 2.1 MAINTENANCE PHILOSOPHY

The basic maintenance philosophy adopted by Northrop for the test bed program was derived by personal contact with Army aviation personnel, and with one significant difference, as outlined in the Department of the Army approved Qualitative Material Requirement for an Automatic Diagnostic and Inspection System for Army Aircraft, dated 11 October 1967. The one change from the QMR approach is utilization of airborne equipment versus the predominantly ground approach addressed in the QMR. In view of the tremendous advances in the state-of-the-art since promulgation of the QMR (1967), and the fact an airborne system tailored for Army helicopters was not available in that time frame, this change from the QMR approach is realistic based on changes in technology.

#### 2.1.1 DIAGNOSIS AND PROGNOSIS

The Maintenance Reporting System accommodates the dual requirements for instant data readout of pertinent information on selected aircraft components, for flight line failure analysis (diagnosis), and accumulation of relevant statistical information for predictive failure analysis (prognosis).

### 2.1.2 REAL TIME CALCULATIONS

A recurring problem for maintenance personnel is a malfunction of a helicopter component in the air, which defies duplication during troubleshooting operations subsequent to the flight. The MRS continuously monitors selected parameters in the air on a real time basis to determine equipment performance and condition.

### 2.1.3 RECORDING RELEVANT DATA

The trap that numerous maintenance systems have fallen into in the past has been the generation of reams of data which required expensive, sophisticated equipment and time for separation of irrelevant/relevant maintenance data. The Northrop MRS records only relevant data based on the detection of multiple levels of component limit exceedance. This data compression technique is illustrated in Figure 2-1. Various levels of abnormality of operation are established for monitored parameters. When the monitored signal changes to a different limit level, this is considered an event and is recorded, along with the time of occurrence, on the maintenance recorder. As long as a parameter stays within this same level of abnormality, no additional data is recorded. If a parameter continues to degrade, or improve, through additional threshold levels, data is again recorded as these new events occur. Thus, airborne distillation of data is automatically performed. These events (level changes) are symptomatic of equipment performance and condition. They are recorded in relation to time of occurrence and therefore relate to the degree and rate of abnormalcy change. Levels of exceedance values for individual helicopter components were taken from approved Army Technical Manuals for the UH-1H. The Army aviator has not been forgotten, in that he may record observed maintenance malfunctions on the MRS recorder by pushing the intercom button on the cyclic stick.

### 2.1.4 SIMPLICITY

The point was previously made that the MRS is a simple system from a skill level viewpoint. It is equally simple from a standpoint of special tool requirements. The MRS can be installed, removed, and disassembled using the tools found in the standard Army mechanics' tool box and/or the UH-1H Organizational Maintenance Supplemental Set.

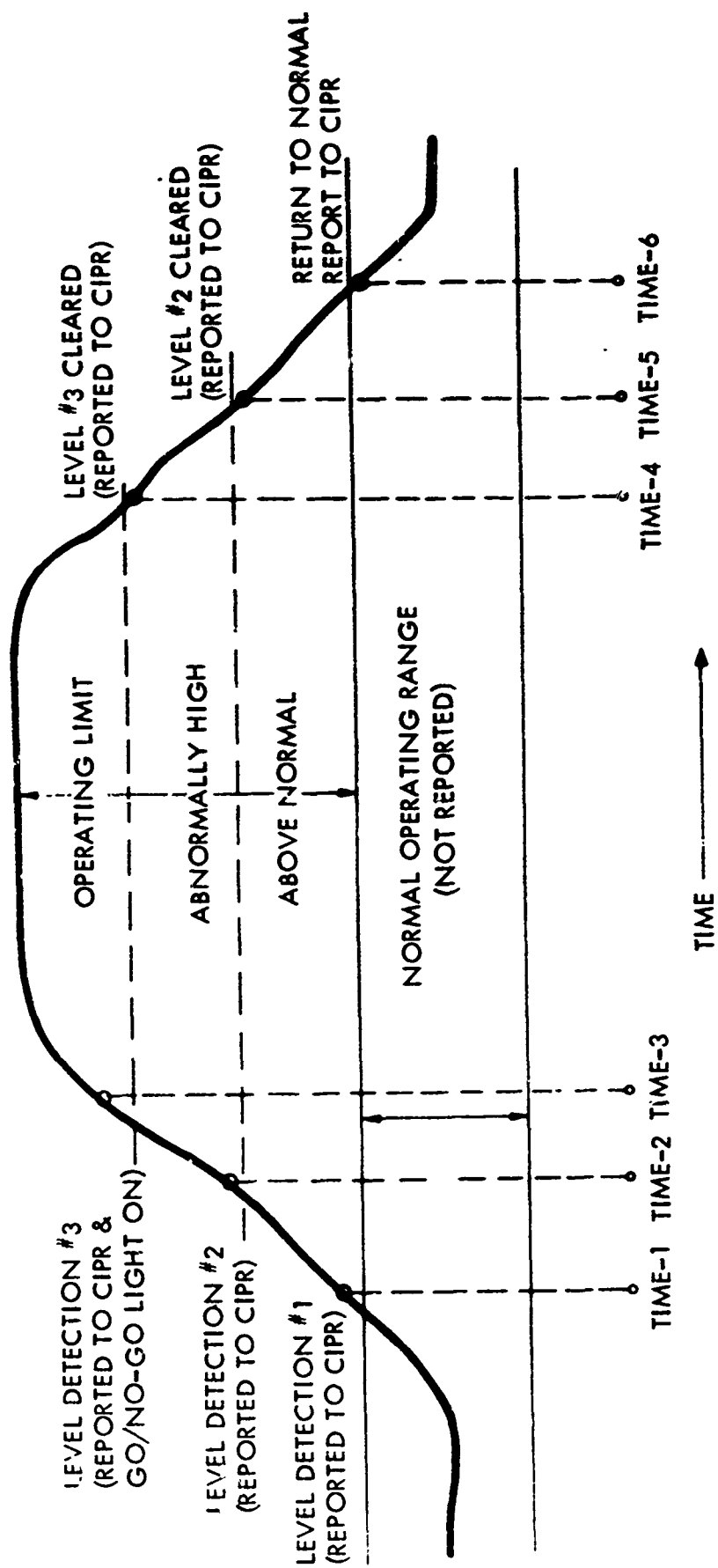


FIGURE 2-1 LEVEL DETECTION CONCEPT

At the OS and DS maintenance levels, a philosophy of remove and replace as necessary will be incorporated to enable existing skill levels to continue to operate and maintain the equipment.

#### 2.1.5 RETROFIT

The application of Modification Work Orders (MWO) to the operational fleet reduces aircraft availability and creates maintenance backlogs. The MRS makes maximum usage of existing aircraft signal sources, with additional sensors added only to discriminate data and isolate the problem. Installation of the MRS on the first UH-1H took only four days with a crew of three personnel. No major modifications to the aircraft were required; only one hole had to be drilled through the engine firewall, and three in the fuselage.

#### 2.1.6 COMPATIBILITY WITH MAINTENANCE CONCEPT

The MRS is compatible with the Army maintenance concept of Organizational, Direct Support, General Support and Depot levels of maintenance. It will also interface with the Maintenance Allocation Chart, and The Army Maintenance Management System (TAMMS) (formerly TAERS). Two additional maintenance functions need to be added to the Maintenance Allocation Charts; these are diagnosis and prognosis.

Calibration requirements upon installation and periodically throughout the life of the aircraft will be accomplished at regularly scheduled inspections where necessary equipment and skills are available. As with the introduction of all avionics systems into Army inventory, special test equipment will be required at the depot level to verify system operation and facilitate fault isolation within the MRS itself.

#### 2.2 ADAPTED "OFF-THE-SHELF" HARDWARE

The basic ground rule for the test bed program was that it was an evaluation of existing state-of-the-art automatic monitoring systems, adapted as necessary for the UH-1H helicopter.

Since 1965 the Northrop Corporation has been engaged in the design, development, and manufacture of airborne monitoring systems, as a natural extension of its decade of work in flight safety avionics including voice warning for Army aircraft. The fallout from this effort was the Integrated

Status Reporting System (ISRS), which is specially applicable to tactical aircraft. The ISRS is the integration of three major subsystems -- inflight safety subsystem, post-flight maintenance data subsystem, and a post-accident investigation data subsystem. Application of the maintenance portion of the ISRS, without adaption, to the UH-1H helicopter would have been an "overkill" in terms of capability. Therefore, the ISRS was tailored specifically to the UH-1H, with consideration given to the UH-1H's complexity, maintenance significant components, size, and weight. The outcome of this tailoring action was the Maintenance Reporting System (MRS), which is pictured in Figure 1-1, of the Introduction and Summary Section.

## **2.3 TEST BED PHASE DESCRIPTION**

The test bed program was reduced to four phases to insure continuity of effort and attainment of specific objectives in each phase. Thus, a building block approach was utilized which provided visibility throughout the test, and achievement of the broad test bed goals. The phases of the program are outlined at this point, with in-depth discussions provided in Sections 4.0 through 7.0.

### **2.3.1 ADAPTATION AND INSTALLATION ENGINEERING - PHASE A**

The objectives of this phase included definization and finalization of all hardware elements of the program for support of the main transmission, 42 and 90 degree gearbox, and engine test cell operations, plus the flight test portion of the test bed program at ARADMAC. Inherent in these objectives was a requirement to study and analyze the UH-1H helicopter regarding parameter selection, sensor selection, signal source analysis and general equipment functional performance requirements for diagnostic and prognostic component analysis.

### **2.3.2 ARADMAC TEST CELL(S) - PHASE B**

Phase B objectives consisted of the development of a data base of good and bad main transmission/gearbox/engine signatures that would enhance the probability of successful intergration and operation of the Maintenance Reporting System in the UH-1H test bed aircraft.

### 2.3.3 PREPARATION FOR FLIGHT TEST - PHASE C

The objective of this phase was to provide a safe and reliable MRS installation in the two UH-1H test bed aircraft.

### 2.3.4 FLIGHT TEST AT ARADMAC - PHASE D

The final phase had as one of its objectives verification of UH-1H/MRS compatibility, in a realistic environment, throughout the flight envelope of UH-1H aircraft operations. A major objective of phase D was to evaluate the system capability to effectively diagnose implanted degraded parts and to prognose parts and LRU's.

## 2.4 IMPLANT SELECTION (DISCREPANT PARTS)

The selection of discrepant parts for the test bed program was carefully controlled by personnel of the U. S. Army Aviation Systems Command, co-located with ARADMAC. Control was exercised not only with regard to the degree of degradation of bearings, engine compressors, nozzles, etc., selected for implant, but also in the area of physical control. Physical control of the parts by serial number was instituted to insure that the same discrepant parts were used in all phases of the test bed program. A detailed examination of implant procedures used during the program is presented in Section 5.6.

## 2.5 TEST SAMPLES

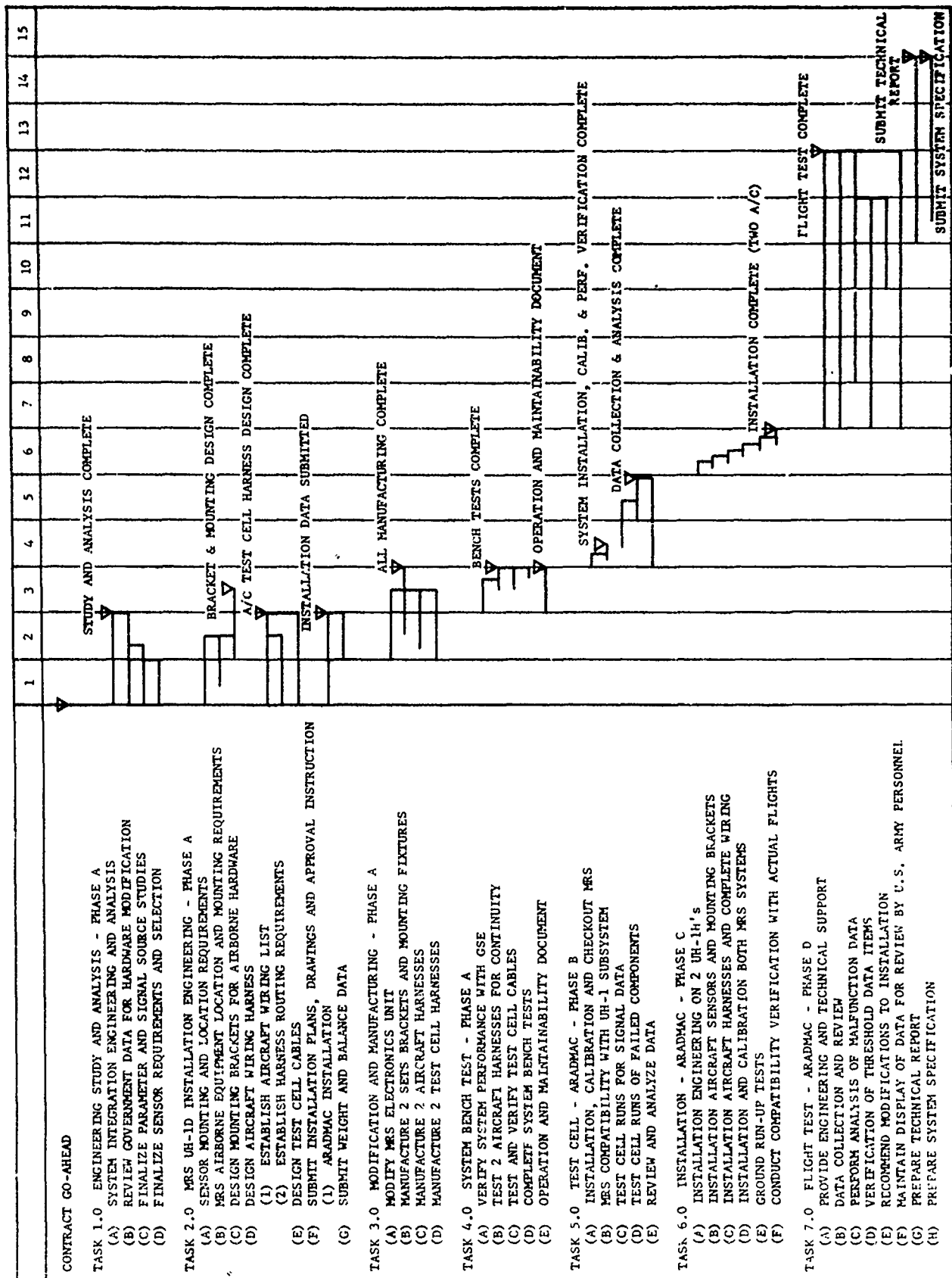
A total of 165 discrepant part runs were accomplished in the main transmission, gear box, and engine test cells. The flight test phase included 61 discrepant part flights, most of which had multiple discrepant parts on the same flight.

## 2.6 PROGRAM SCHEDULE

A recapitulation of the program schedule, by phase, is addressed in Figure 2-2.

## 2.7 MONITORING REQUIREMENTS

The following presents an overview of monitoring requirements with amplification contained in Section 3.3.



**FIGURE 2-2 PROGRAM SCHEDULE**

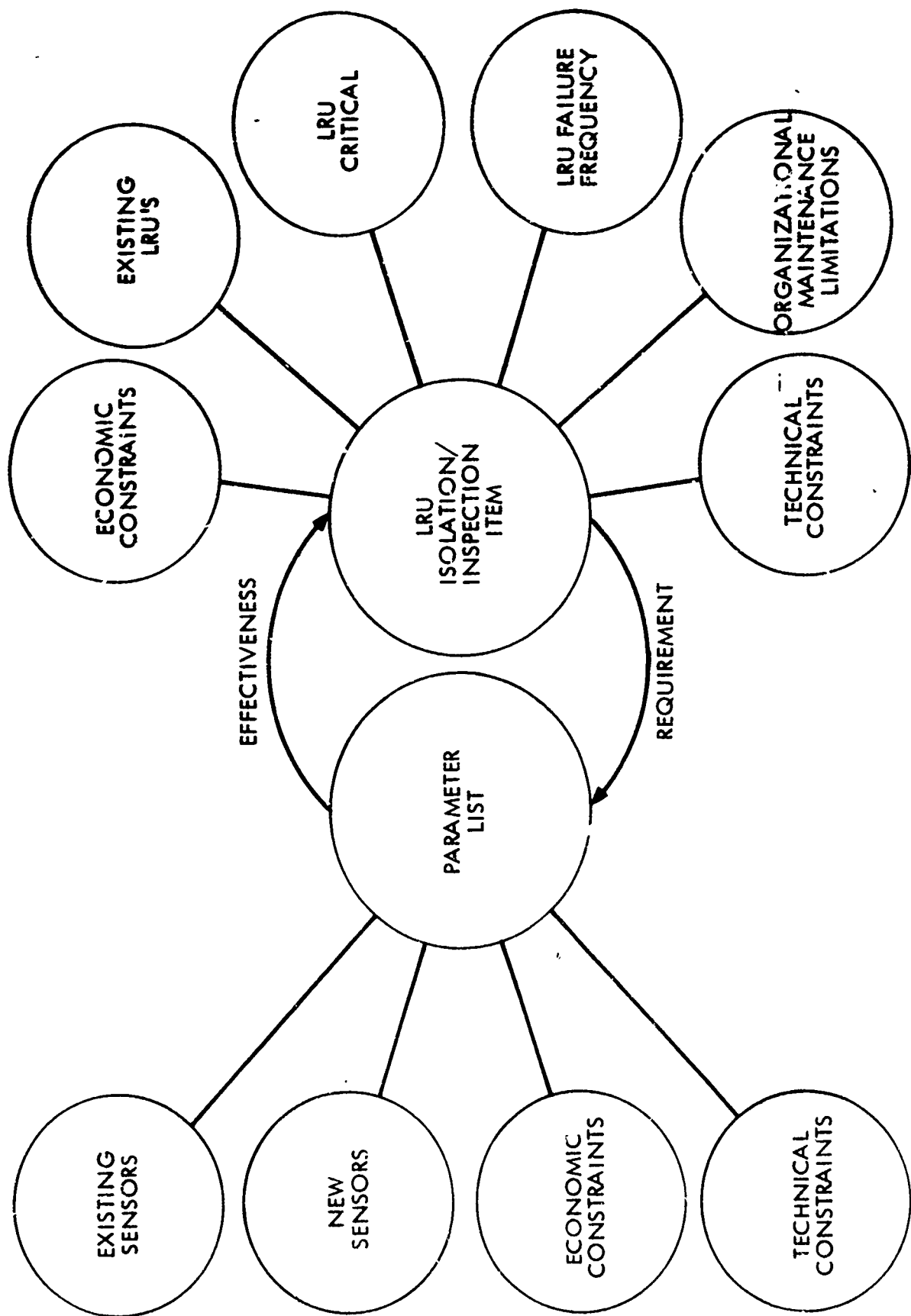


FIGURE 2-3 SYSTEM MECHANIZATION INTERRELATIONSHIPS

### 2.7.1 PARAMETER/LRU SELECTION

The selection of parameters to be monitored by Northrop's MRS, as well as the selection of line replaceable units to be isolated/identified, was a compromise among many factors. Both elements, the parameters and the LRU's, have their own constraints and both are related to each other. The complex crossflow of requirements and effectiveness is depicted in Figure 2-3. The principal link between these two factors is the MRS mechanization. Final selection of system design detail was accomplished by balancing the ratio of requirements and effectiveness results.

### 2.7.2 INSPECTION REQUIREMENTS

In keeping with the simplicity of the MRS, inspection requirements as identified in TM 55-1520-210-20 (Organizational Maintenance Manual) were analyzed and accommodated by the MRS. Thus, Army personnel were able to quickly understand and utilize MRS outputs based on their training and familiarization with standard Army TM's.

### 2.7.3 DIAGNOSIS

The problem of limited diagnostic talent in aviation mechanics has long been recognized by the Army. The technique of "trouble shooting with parts" is fully documented based on return of faulty diagnosed components to depot levels of maintenance. The monitoring approach selected for the MRS permits automatic isolation of a malfunction down to the LRU level. This capability facilitates remove and replace functions at the organizational level of maintenance, particularly in forward areas. This item is a key requirement of the Maintenance Support Positive portion of the Department of the Army Logistics Offensive Program.

### 2.7.4 PROGNOSIS

Prognosis as applied to Army aircraft maintenance is the science of predicting the remaining usable life of an item. Prediction of remaining life starts with a new or overhauled component, such as an engine. A new or overhauled engine has a predicted life which is usually the historically determined average for a significant sample of components. In graphic form, idealistically, historical health data will be a straight line until degradation starts, then

the line will start to curve upward to a failure point. The objective is to prognosticate or predict a point on the upward swing of the health line where removal action on a component can be initiated prior to failure. The MRS has the capability of providing prognostic information through its continuous monitoring of aircraft health, using the levels of exceedance approach presented in Figure 2-1. This is accomplished by establishing the thresholds or levels at points that correspond to a typical time remaining curve for a component. The method, in general, relies on a similarity in wear out curves. Figure 2-1A may further help to clarify this approach.

Time remaining ( $T_R$ ) as seen on the figure is directly related to selected threshold limits and can be determined by measuring the expended useful time ( $T_e$ ) and comparing with the expected time between overhaul ( $T_{BO}$ ). Conversely, by sensing the thresholds relation to its normal wear out curve, an exceedance of limit implies remaining life. As data is continually gathered by operation of the system, time remaining criteria (and corresponding thresholds) may be adjusted to provide a more accurate indication. The number of thresholds employed will also have an effect on the accuracy of the time remaining value. It should be pointed out that the levels selected may be based on more than one parameter and may even represent a cumulative effect such as the time/temperature life limiting relationship for some engines.

This data is available to the helicopter crew chief immediately after landing at the flight line. MRS monitored components that have started to degrade are immediately obvious to the crew chief by looking at the data printout which lists parameter exceedance values keyed to time. The maintenance officer may then initiate removal action on components prior to failure in flight.

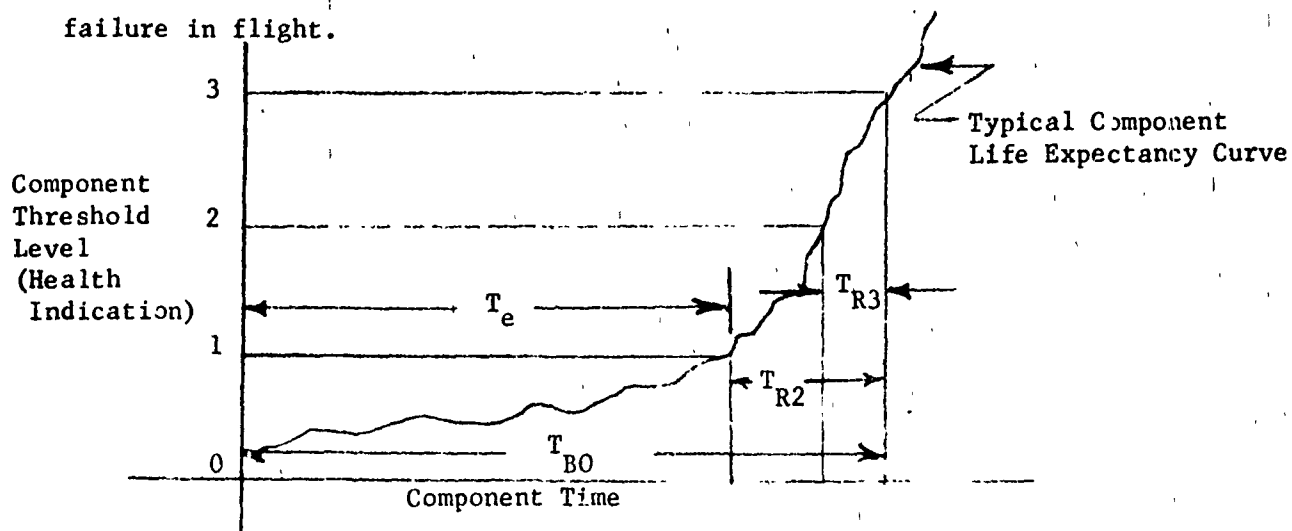


FIGURE 2-4 RELATIONSHIP OF THRESHOLD TO COMPONENT TIME REMAINING

### 2.7.5 FAULT ISOLATION

This area was alluded to in paragraph 2.7.3, but, in view of its impact on and interface with many aspects of Army aviation logistics, requires additional emphasis.

The Department of the Army Logistics Offensive Program (LOP) includes two key elements which influenced the test bed fault isolation approach. These LOP elements are the Maintenance Support Positive (MS+) concept and the expanded Direct Exchange (DX) procedure. MS+ places heavy emphasis on LRU removal and replacement in forward areas, rapid retrograde of repairable components to the appropriate maintenance level, and quick repair by that maintenance level. MS+ is to be supported by the DX program which must have a stock of serviceable components for over-the-counter exchange for the components removed in the forward areas. These programs obviously must be mutually self-supporting. The key to achieving this self-support is positive isolation of a faulty component. Positive fault isolation of an LRU will facilitate factual removal and replacement actions in forward areas; assist in the maintenance management of repairables by providing information that permits retrograde of a repairable to the maintenance level (DS, GS or Depot) that can effect the quickest repair and turnaround; and will drastically reduce the troubleshooting time currently expended on repairables by the various maintenance levels due to unknown failure modes. Rapid repair of components will, in turn, ensure a supply of serviceable components to support the DX program.

Analysis by Northrop of the real world Army logistical considerations outlined above led to the conclusion that they should be accommodated in the test bed program, if the results were to have maximum application to normal Army operations. Thus, the MRS was tailored to provide positive fault isolation of selected LRU's normally removed and replaced in forward areas of a theater of operations. Additional details on fault isolation are provided in subsequent sections of this report.

## SECTION 3

### 3.0 MAINTENANCE REPORTING SYSTEM (MRS) FOR THE TEST BED PROGRAM

The MRS is a total system approach in that it accommodates the objectives of the test bed program relative to Inspection, Diagnosis and Prognosis. These objectives are satisfied by selection of an airborne, continuous monitoring technique. Continuous monitoring of aircraft parameters is particularly significant for data gathering on maintenance malfunctions that occur in the air but cannot be duplicated during troubleshooting operations on the ground subsequent to a flight. For example, a compressor surge that occurs briefly in the air would be recorded by the MRS. This condition could not be detected by a ground plug-in system that does not continuously monitor, nor by a system that periodically samples aircraft parameter outputs. Details of the MRS operation are described below.

#### 3.1 SYSTEM OPERATION

The basic airborne system is composed of an Electronics Unit (EU), a Continuous Inflight Performance Recorder (CIPR), and both new and existing aircraft sensors. Accumulated maintenance data is recovered from the airborne system by use of the Data Recovery Unit (DRU). Figure 3-1 depicts in block form the relationship of the major parts of the system.

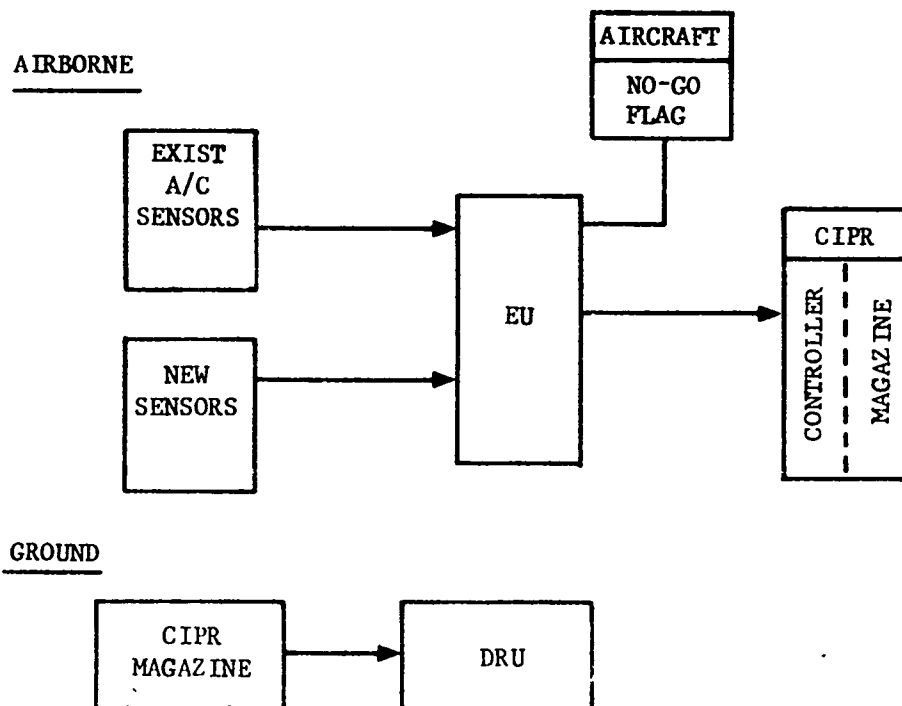


FIGURE 3-1 SYSTEM BLOCK DIAGRAM

During flight, signals from sensors which monitor significant aircraft parameters (see Table 3.1) are conditioned to make them compatible with the processing and computation circuits of the EU. The processing circuits convert conditioned signals to digital form, perform calculations, detect exceedance of limits, establish logic relationships of monitored parameters, provide a status memory of maintenance conditions, and codify and adopt the maintenance data for storage by the CIPR.

Table 3.1A lists the accuracies of the added sensors. The true accuracy of a sensor is a function of many environment and employment factors. A nominal accuracy for the sensors has been derived from the manufacturer's data sheets. The accuracy of the overall MRS can only be expressed in terms of a generalization of the accuracies of specific operations. An unmodified parameter which is outputted directly will have an accuracy which is the Root of the Sum of the Squares (RSS) of the accuracies of the sensor and the electronic operations. A parameter which is the arithmetic result of two or more data inputs will have an accuracy which is the RSS of the input factors. As an example, corrected CPR is a function of ambient air pressure (Pamb), Compressor Discharge Pressure (CDP), compressor speed ( $N_1$ ) and Outside Air Temperature (OAT). These parameters are determined to the following general full scale accuracies including sensor and electronic accuracies.

$$\begin{aligned} P_{amb} &= \pm 1\% \\ CDP &= \pm 1\% \\ N_1 &= 0.7\% \\ OAT &= 1\% \end{aligned}$$

The generalized accuracy for the determination of Corrected Compressor Pressure Ratio is  $\sqrt{1^2 + 1^2 + .7^2 + 1^2} = \pm 1.85\%$ . This can be extrapolated to an overall assessment of the MRS system accuracy as  $\pm 2.0\%$ .

Digitized maintenance data transmitted from the EU is recorded on the magnetic tape of the CIPR magazine by recording and control circuits within the CIPR controller. Maintenance conditions are recorded on the main channel, key parameter quantitative data is recorded on the engineering channel, and time pulses (generated within CIPR) are recorded on the time channel.

At the completion of a flight, data stored by the CIPR can be recovered by removing the CIPR magazine from the aircraft and playing back the contents of the magazine using the DRU. The DRU provides a printed record of maintenance items that have occurred during flight, including a simultaneous print of elapsed flight time to aid maintenance action. Each maintenance item mechanized by the MRS is represented by an alphanumeric (maintenance) code and the post-flight printout of the DRU displays this code. Maintenance action is determined by the possible cause--corrective action information listed for each code in the MRS Diagnostic Charts. Materiel conditions described in the diagnostic charts are listed in Table 3.2. An example of data recovered from the maintenance (main) channel of the CIPR is shown below for a flight conducted 30 July 1971. A detailed explanation of the alpha-numeric code printout is presented in Section 3.3.4.

End of Flight	K11-.059.6	End Coastdown Data
	....01-128	Coastdown Time
	K11+.059.6	Start Coastdown Data
	A53-.039.5	Engine Overspeed Return to Normal
	A53+.039.5	Engine Overspeed
	B61-.025.3	Engine CPR Calculator Return to Normal
	B61+.025.1	Engine CPR Calculator 1st Level
	B61-.003.5	Engine CPR Return to Normal
	B62-.003.5	Engine CPR Return to Normal
	B62+.003.4	Engine CPR Calculator 2nd Level
	B61+.003.4	Engine CPR Calculator 1st Level
Start of Flight	H41A.002.5	A/C Liftoff
	F01+.000.7	MRS Power On

B61 and B62 printouts show that the first two levels of engine compressor pressure ratio calculator have been exceeded, indicating that the engine has a serious compressor malfunction. The basic engine should be removed and replaced.

A53 occurrence indicates that the engine was operated at greater than 6640 RPM with gas producer speed greater than 91% for longer than the allowable 3 seconds. Inspections should be performed as called out in TM's.

K11 printouts indicate start and end of quantitative data. The only printout of this sort on the main channel, between K11 prints, is a number indicating relative coastdown time.

Data from the engineering channel is recovered in the same manner as the maintenance data from the main channel. These data were used as backup data for the test bed program to verify performance of the engine health calculator and provide insight into data trends. It was collected under three specific conditions: (a) when a malfunction occurred, (b) when specific aircraft flight conditions were satisfied, and (c) every 3.2 minutes of flight time. Table 3.3 lists the quantitative outputs which were recorded on the CIPR engineering channel. A few of the outputs listed were changed at various times during the test program to acquire specific data about other parameters.

**TABLE 3.1 MRS/UH-1H MONITORED PARAMETERS**

<u>Parameter</u>	<u>Added Sensor</u>
Exhaust Gas Temperature (EGT)	
Gas Producer Speed (RPM) $N_1$	
Rotor Speed (RPM)	
Interstage Airbleed System (Bleed Band)	X
Torque Pressure	
Air Induction System (Engine Air Filter Operation)	
Compressor Discharge Pressure	X
Ambient Pressure	X
Inlet Guide Vane Position	X
Engine Fuel Flow	X
Vibration Engine Compressor	X
Vibration Engine Combustor	X
Vibration Engine Turbine	X
Fuel Boost Pump On (Pilot's Switch)	
R.H. Fuel Boost Pump (Flow Switch)	
L.H. Fuel Boost Pump (Flow Switch)	
Main Fuel Filter (Diff. Pressure Switch)	
Engine Fuel Pressure	
Starting Fuel Solenoid	
Fuel Pressure	
Engine Governor Switch Emergency Position	
Engine Governor Manual Control	
Engine Oil Pressure Low (Switch)	
Engine Oil Pressure (Transmitter)	
Engine Chips Detector (Acc. Gear Box)	
Engine Oil Filter (Diff. Pressure Switch)	X
Engine Oil Temperature	
Engine Oil Cooler In and Out Temperature Operation	X
Engine #2 Bearing Scavenge Oil Temperature	X
Engine #3 & #4 Bearing Scavenge Oil Temperature	X
Engine Accessory Drive Gear Box Pressure	X
Transmission Oil Temperature Switch	
Transmission Oil Pressure Low (Switch)	
Transmission Oil Pressure (Transmitter)	
Transmission External Filter (Diff. Pressure Switch)	X

**Table 3.1 (Continued)**

<u>Parameter</u>	<u>Added Sensor</u>
Transmission Internal Filter (Diff. Pressure Switch)	X
Transmission Oil Cooler In & Out Temperature	X
Transmission Chips Detector	
Transmission Lateral (Cover) Vibration	X
Transmission Normal (Mast) Vibration	X
90° Gear Box Chips Detector	
42° Gear Box Chips Detector	
90° Gear Box Lateral Vibration	X
90° Gear Box Normal Vibration	X
42° Gear Box External Temperature	X
42° Gear Box Internal Temperature	X
90° Gear Box External Temperature	X
90° Gear Box Internal Temperature	X
Hydraulic Pressure Low (Switch)	
Hydraulic Relief Valve Failure (Pressure Switch)	X
Hydraulic Fluid Temperature	X
Hydraulic Control Solenoid Power	
Essential and Primary Bus Voltage	
Main Inverter Operation (Switch & Volt)	
Spare Inverter Operation (Switch & Volt)	
Main Generator Operation (Switch & Volt)	
Standby Generator Voltage	
28 Volt A.C. Transformer Voltage	
Inverter Bus Voltage (Low ) (A.C. Failure Relay)	
Standby Generator On Switch Position	
Pilot's Area Normal Acceleration	X
Pilot's Area Lateral Acceleration	X
Ambient Air Temperature	X
Pilot's Voice	
Transmission Acceleration Input Normal Vibration*	X
Transmission Input Longitudinal Vibration*	X
Transmission Acceleration Output*	X
Transmission Output Longitudinal Vibration*	X
42° Longitudinal Acceleration*	X
42° Normal Acceleration*	X

\*Aircraft 67-17448 only.

TABLE 3.1A ADDED SENSOR ACCURACIES

<u>Type</u>	<u>No.</u>	<u>Nominal Accuracy</u>	<u>Manufacturer &amp; Type</u>	<u>Typical Usage</u>
Pressure Xducer	2	$\pm 0.75\% \pm 0.01\%$	Statham, PA208TC-( )	CDP & Pamb
Pressure Xducer	1	$\pm 0.75\% \pm 0.01\% / ^\circ\text{F}$	Statham, PA208TC-( )	GB Oil Pressure
Pressure Xducer	1	$\pm 0.75\% \pm 0.01\% / ^\circ\text{F}$	Statham, PG132TC-50	Fuel Pressure
Accelerometer	13	(Note 1)	Endevco, 6222M3	Engine & Power Train Vibration
Temperature	4	$\pm 0.1^\circ\text{C}$	Rosemont, 118G	G.B. Temp.
Temperature	4	$\pm 0.5\%$	Lewis et al, MS28034-3	Eng. Oil Temp.
Temperature	1	$\pm 0.5\%$	Lewis, 56B32	Hydraulic Temp.
Temperature	1	$1^\circ\text{C}$	Lewis, 54B	OAT
Accelerometer	2	$\pm 1\%$	Statham, AJ-43	Pilot's Acceleration
Position Potentiometer	1	$\pm 0.25\%$	CIC, 78	IGV Position
Flow Meter	1	$\pm 0.5\%$	Foxboro, 1/2-2-81-200	Fuel Flow
Pressure Switch	1	N/A	Custom Component, 41D23	$\Delta P$ , Eng Oil Filter
Pressure Switch	2	N.A	Custom Component, 42D254	$\Delta P$ , Xmsn Oil Filter
Pressure Switch	1	N/A	Custom Component, 98G191	Hydraulic Pressure
Position Switch	1	N/A	Honeywell, 6HM1-1	Airbleed Closure

(Note 1) Sensitivity  $[\text{pc/g}]$   $\pm 5\%$ ;  $-5\%/+10\%$ ,  $-100^\circ\text{F}$  to  $500^\circ\text{F}$ ; Nonlinearity,  $\pm 1\%$

TABLE 3.2 MAINTENANCE CODES

Maintenance Code	Aircraft Condition
A 1 1	
2	
3	EGT > 760°C
A 2 1	
2	EGT > 627°C for 30 minutes or longer
3	EGT > 676°C for 5 seconds
A 3 1	
2	
3	N1 > 101.5%
A 4 1	
2	
3	N2 > 7180 RPM
A 5 1	
2	
3	N2 > 6640 RPM for 3 seconds and N1 > 91%
A 6 1	
2	
3	N1 < 91% and N2 > 6750 RPM
A 7 1	
2	
3	EGT > 760°C or EGT > 676°C for 5 seconds or longer
A 8 1	TORQUE > 61 psi
2	TORQUE > 54 psi
3	TORQUE > 50 psi
A 9 1	
2	
3	IGV > 60% and N1 > 87% or IGV < 80% and N1 < 87%
A 0 1	
2	MAIN ROTOR > 330 RPM
3	MAIN ROTOR > 356 RPM
B 1 1	
2	
3	N1 > 87% and Interstage Airbleed Switch not closed for 7 seconds
B 2 1	
2	
3	Air Induction System Switch clogged filters
B 3 1	
2	
3	Transmission Vibration

**TABLE 3.2 MAINTENANCE CODES (Continued)**

<u>Maintenance Code</u>	<u>Aircraft Condition</u>
B 4 1	
2	
3	Engine Vibration
B 5 1	
2	
3	
B 6 1	CPR CALC < 185
2	CPR CALC < 180
3	CPR CALC < 175
B 7 1	EGT CALC < 150
2	EGT CALC < 140
3	EGT CALC > 185
B 8 1	
2	
3	Spare
B 9 1	
2	
3	Spare
B 0 1	
2	
3	Spare
C 1 1	
2	
3	Elec. Fuel Boost Pump On and Rt Fuel Boost Pump has no flow
C 2 1	
2	
3	Left Fuel Boost Pump Switch
C 3 1	
2	
3	Main Fuel Filter Clogged
C 4 1	
2	
3	Main Fuel Press. Low and Fuel Press. between 5 and 35 psi
C 5 1	
2	
3	Fuel Press. < 5 psi or Fuel Press > 35 psi
C 6 1	
2	
3	Loop > 50 RPM

**TABLE 3.2 MAINTENANCE CODES (Continued)**

<u>Maintenance Code</u>	<u>Aircraft Condition</u>
C 7 1	
2	
3	Elec Fuel Boost Pump Not On
C 8 1	
2	
3	Starting Fuel Solenoid Open
C 9 1	
2	
3	Gov Switch in Emerg
C 0 1	Fuel Flow CALC > 205
2	Fuel Flow CALC > 210
3	Fuel Flow CALC > 215
D 1 1	
2	
3	Eng Oil Press Low and Eng Oil Temp < 93°C
D 2 1	
2	
3	Eng Oil Press > 100 psi
D 3 1	
2	
3	Chips - Access Drive Gear Box
D 4 1	
2	
3	Eng Oil Filter Clogged
D 5 1	
2	
3	Eng Oil Temp > 93°C and Eng Oil Press Low
D 6 1	
2	
3	Eng Oil Cooler $\Delta T$ Low and XMSN Oil Temp Not Hot and Eng Oil Press Not Low and Eng Oil Temp > 93°C
D 7 1	
2	
3	No. 2 Bearing Differential Temp > 122°C
D 8 1	
2	
3	No. 3 & 4 Bearing Differential Temp > 122°C

**TABLE 3.2 MAINTENANCE CODES (Continued)**

<u>Maintenance Code</u>	<u>Aircraft Condition</u>
D 9 1	
2	
3	Spare
D 0 1	
2	
3	Accessory Gear Box Press > 3.5 psi
E 1 1	
2	
3	XMSN Oil Temp Hot
E 2 1	
2	
3	XMSN Oil Temp Hot and Eng Oil Temp > 93°C
E 3 1	
2	
3	XMSN Oil Press Low and XMSN Oil Temp Not Hot
E 4 1	
2	
3	XMSN Oil Press > 70 psi
E 5 1	
2	
3	XMSN Internal Oil Filter Clogged
E 6 1	
2	
3	XMSN Oil Temp Hot and Eng Oil Temp < 93°C and XMSN Oil Press Not Low and XMSN Oil Cooler $\Delta T$ Low
E 7 1	
2	
3	Chips in XMSN
E 8 1	
2	
3	Spare
E 9 1	
2	
3	Spare
E 0 1	
2	
3	XMSN Oil Press Low and XMSN Oil Temp Hot

TABLE 3.2 MAINTENANCE CODES (Continued)

<u>Maintenance Code</u>	<u>Aircraft Condition</u>
F 1 1	
2	
3	Chips in 42° Gear Box
F 2 1	
2	
3	Chips in 90° Gear Box
F 3 1	
2	
3	42° Gear Box Vib
F 4 1	
2	
3	42° Gearbox Differential Temp High
F 5 1	
2	
3	90° Gearbox Differential Temp High
F 6 1	
2	
3	Spare
F 7 1	
2	
3	Spare
F 8 1	
2	
3	90° Gear Box Vib
F 9 1	
2	
3	XMSN External Oil Filter Clogged
F 0 1	MRS Power On
2	
3	
G 1 1	
2	
3	Essential Bus < 23V
G 2 1	
2	
3	Main Gen Fail
G 3 1	
2	Standby Gen < 23.4V
3	Essential Bus < 15V

**TABLE 3.2 MAINTENANCE CODES (Continued)**

<u>Maintenance Codes</u>	<u>Aircraft Condition</u>
G 4 1	
2	
3	Essential Bus > 31V
G 5 1	
2	
3	Instrument Bus < 10 VAC and Inverter Not Failed
G 6 1	
2	Main Inverter Not On
3	Inverter Volt < 100V and Main Inverter On
G 7 1	
2	
3	Inverter Volt > 130V and Main Inverter On
G 8 1	
2	
3	Inverter Volt < 100V and Spare Inverter On
G 9 1	
2	
3	Inverter Volt > 130V and Spare Inverter On
G 0 1	
2	
3	Essential Bus < 23V and STBY Rev Curr Relay- Open and Main Gen Failed
H 1 1	
2	
3	HYD ΔTemp > 16.7°C and HYD Press Not Low
H 2 1	
2	
3	HYD Relief Valve Fail
H 3 1	
2	
3	Hyd Cont Valve Not Closed and Hyd Press Low
H 4 1	Aircraft Lift Off
2	
3	
H 5 1	
2	Hyd Cont Valve Closed and Hyd Press Low
H 6 1	
2	
3	Spare

**TABLE 3.2 MAINTENANCE CODES (Continued)**

<u>Maintenance Code</u>	<u>Aircraft Condition</u>
H 7 1	Spare
2	
3	
H 8 1	Spare
2	
3	
H 9 1	Spare
2	
3	
H 0 1	Spare
2	
3	

**TABLE 3.3 ENGINEERING CHANNEL QUANTITATIVE DATA**

NI RPM	Gas Produce Speed
K CPR	Engine CPR Calculator Output
KW <sub>f</sub>	Engine Fuel Flow Calculator Output
KEGT	Engine EGT Calculator Output
364 Brg ΔT	Differential Temperature of #364 Bearings
2 Brg ΔT	Differential Temperature of #2 Bearing
Eng Oil Temp	Engine Oil Cooler Output Temperature
42° ΔT	42° Gear Box Differential Temperature
90° ΔT	90° Gear Box Differential Temperature
EGT	Exhaust Gas Tail Pipe Temperature
Torque	Engine Output Torque
N2	Engine Power Shaft RPM
Pamb	Ambient Pressure
CDP	Compressor Discharge Pressure
OAT	Ambient Temperature
XMSN Oil Temp	Transmission Oil Cooler Output Temperature
XMSN Oil Pressure	Transmission Oil Pressure
400 Hz	Autotransformer Output Voltage

## 3.2 HARDWARE DESCRIPTION

### 3.2.1 AIRBORNE EQUIPMENT

The Electronics Unit (EU) (see Figure 3-2) contains the electronic circuits for signal conditioning, processing, digitizing, coding, and outputting of maintenance data. Nineteen printed circuit cards contain the components necessary for the various circuit functions performed by the EU and another printed circuit board provides interconnections between circuit boards. The metal housings provides the structural support for the printed circuit cards as well as other components mounted to it. A metal wedge at the rear and two curved brackets in front provide a means of installing and locking the EU in a mounting base (see Figure 3-3). Two input connectors are located at the rear and a test connector is on the front. Also on the front are an aircraft no-go indicator which signals critical LRU impending or actual failure, an MRS failure indicator (internal BIT signal), a pushbutton indicator reset switch, an engine cumulative running time meter, an engine N1 cumulative overspeed events counter, and an engine cumulative overtemp events counter. The EU weighs approximately 11 pounds and its size is 11x7x6 inches.

The Continuous Inflight Performance Recorder (CIPR) (see Figure 3-4) is comprised of two parts--a magazine and a controller which are essentially the same as the AN/ASH-23. The magazine is a continuous reel-to-reel, 1/4-inch magnetic recording tape transport and recording head assembly. A cast aluminum housing provides stability and a machined face for correctly aligning a coupling to the controller. Four quick disconnect fasteners facilitate rapid removal of the magazine from the controller using a standard Army aviation screwdriver.

The controller also has a cast aluminum housing which supports 3 printed circuit boards, a gear motor assembly train, and a connector which mates to the magazine. Components mounted on the printed circuit boards provide motor drive and control, digital and audio record circuits, line receiver circuits, and voltage regulation.

When both parts of the CIPR are connected, they weigh approximately 3.5 pounds and the size (not including the mounting flange) is 4.3 inches in diameter by 5.8 inches long. Figure 3-5 presents a view of the Maintenance Reporting System installed in a UH-1H helicopter.

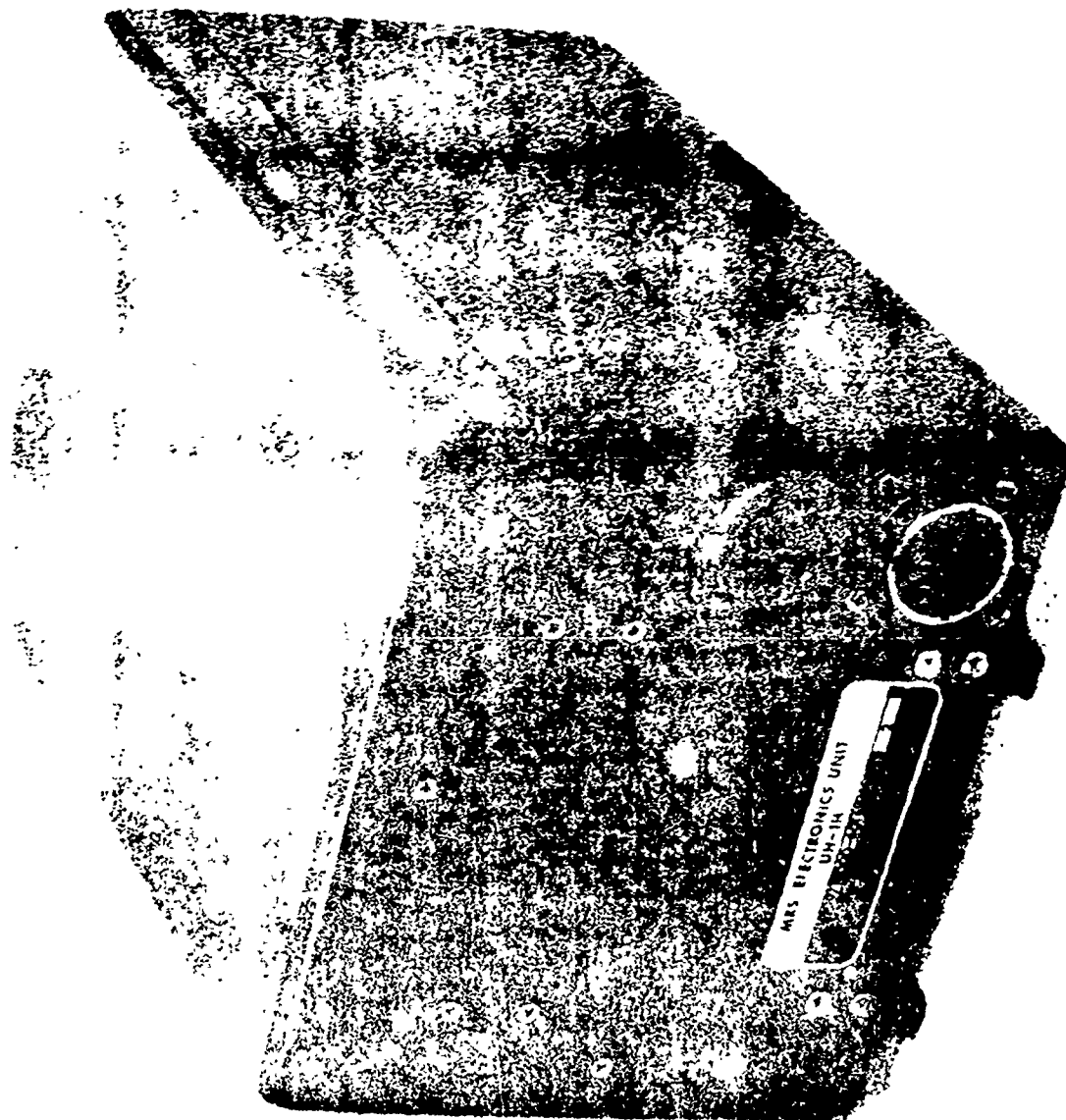



FIGURE 3-2 MRS ELECTRONIC UNIT - P/N 09718000

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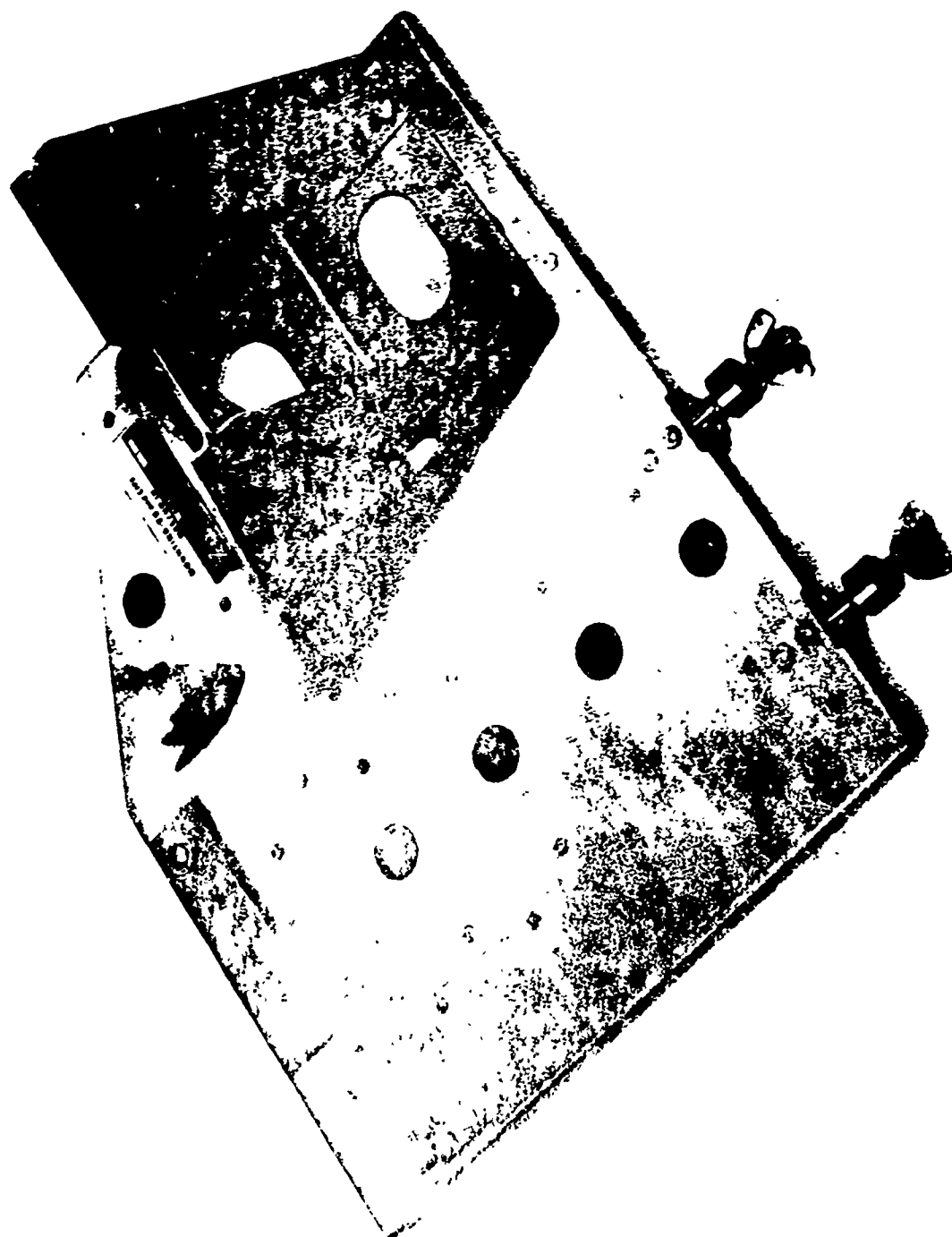


FIGURE 3-3 MOUNTING-EU AND CIPR MRS/UH-1H - P/N 09718070



FIGURE 3-4 MAINTENANCE RECORDER (CIPR)



FIGURE 1-5 MRS INSTALLATION

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best available copy.

Both the CIPR and the EU are mounted in the aircraft using the mount shown in Figure 3-3. No special damping of the mount is required.

### 3.2.2 GROUND EQUIPMENT

MRS ground equipment consists of two items of hardware -- the Data Recovery Unit (DRU) and the MRS Functional System Simulator (FSS). The DRU provides for recovery of maintenance data from the CIPR tape magazine. The FSS is used in conjunction with the DRU to provide complete check out of all MRS Electronics Unit and CIPR functions in a bench test environment.

The DRU (see Figure 3-6) is portable and capable of recovering data at planeside. It is larger than necessary for the UH-1H data recovery requirements, but as previously mentioned, was used to demonstrate an off-the-shelf equipment capability. The CIPR can be mounted directly to the control panel of the DRU for playback of stored maintenance data which is displayed on a printout from a printer also mounted on the control panel. The unit contains the switches and circuits necessary to provide a fast rewind capability and normal playback speed in the CIPR. Circuits for decoding the digital playback data and for controlling the printer are contained on circuit boards within the unit.

Audio information can also be recovered from the audio channel of the CIPR and can be monitored by a headset or the speaker on the panel of the unit.

The MRS FSS provides signals that simulate the aircraft sensors when testing the MRS. Controls for varying the signals and changing the condition of EU inputs are mounted by functional group on the front panel (see Figure 3-7). A power supply, signal oscillators, variable resistances, impedance simulating circuits, and voltage scaling circuits necessary for simulating signals are contained on subassemblies within the simulator. Cabling and switches on the back panel provide the additional capability of using the simulator in "series" with the EU to simulate any or all inputs received when the EU is installed in an aircraft.

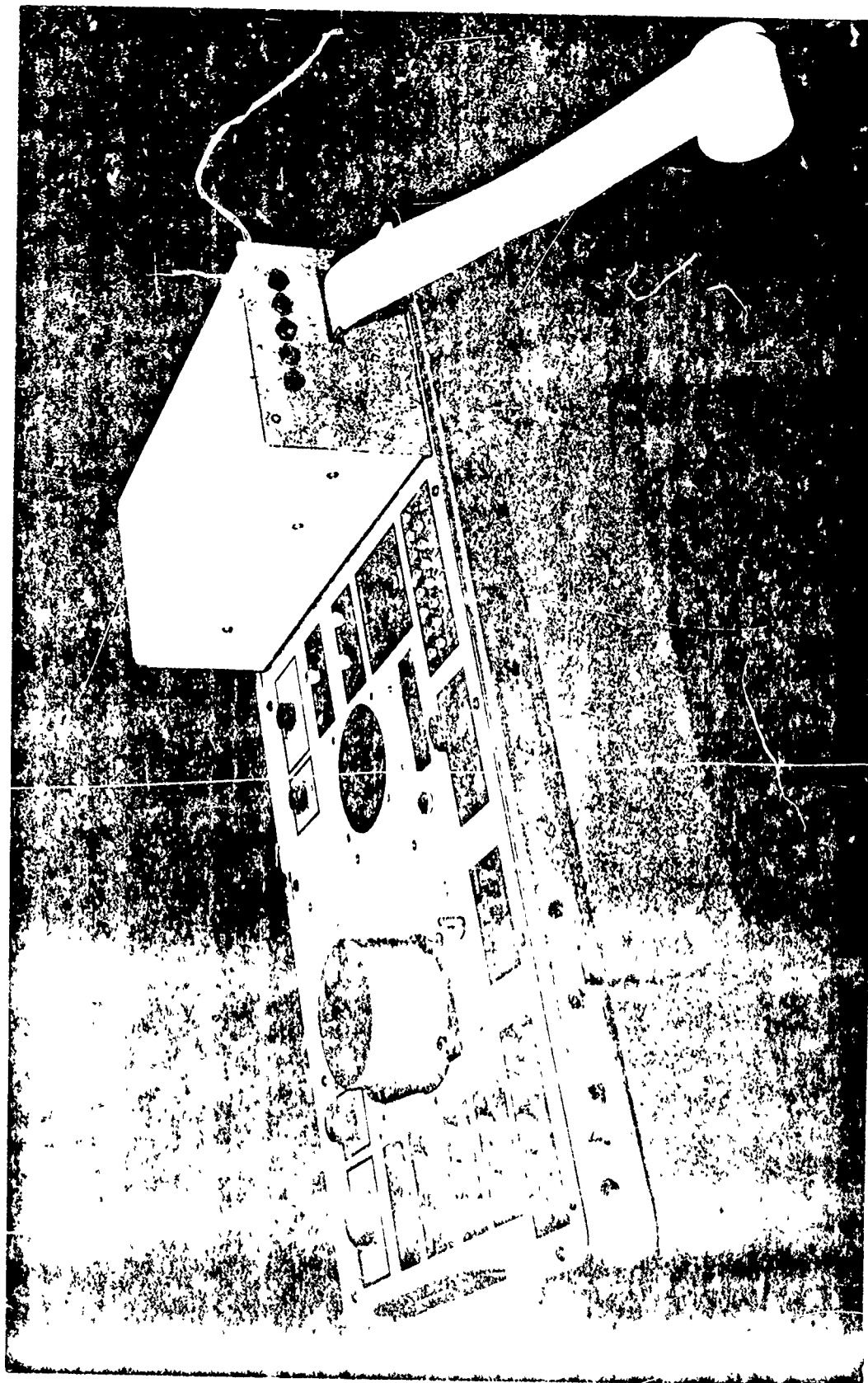


FIGURE 3-5 DATA RECOVERY UNIT (DRU)

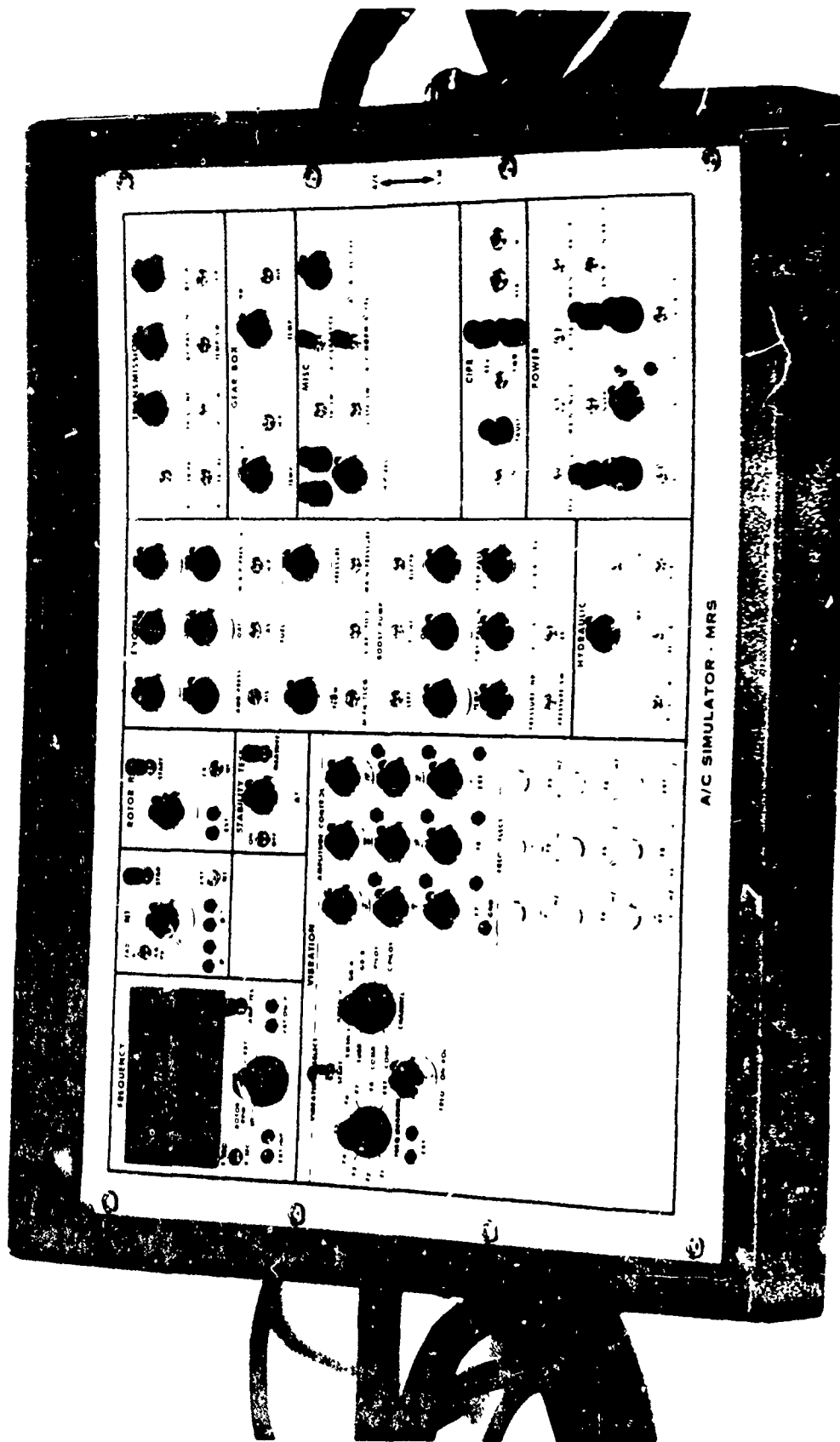


FIGURE 1-7 MRS FUNCTIONAL SYSTEM SIMULATOR - P/N 09718500 (FRONT VIEW)

### 3.3 MONITORING METHODS

#### 3.3.1 VIBRATION MONITORING

Vibration mechanization in the early part of the test bed program utilized a single frequency narrowband technique of monitoring which proved to be inadequate for detecting faulty components. Subsequently, a method which improved detection capability, particularly in the more complex realm of flight environment, was incorporated into the MRS. This method is called the ratio method of vibration monitoring.

Briefly, the ratio method gets its name from the manner in which the data is analyzed. As shown in Figure 3-8, the wideband accelerometer data is fed into a narrow bandwidth spectrum analyzer.

The peak energy occurring in Band "B" is divided by the peak energy occurring in Band "A", resulting in a ratio. This ratio is dimensionless and is therefore not effected by amplitude calibration errors. The ratio also tends to normalize against changes in power levels transmitted through the machine. Results occurring from the incorporation of this technique in the MRS are presented in Section 7.9.

Mechanization of the vibration monitoring and detection method uses inputs from four accelerometers. Each accelerometer is connected to the monitoring circuits by a multiplexer and is sampled once every minute (see figure 3-9). During each sample each accelerometer input is scanned at least twice (engine and transmission accelerometers require more scans). During the first scan the voltage controlled oscillator (VCO) sweeps through a predetermined frequency band and stores the peak value obtained in the band. During the second scan the VCO sweeps through a different predetermined frequency band and compares the peak value of the second sweep with that stored for the first sweep.

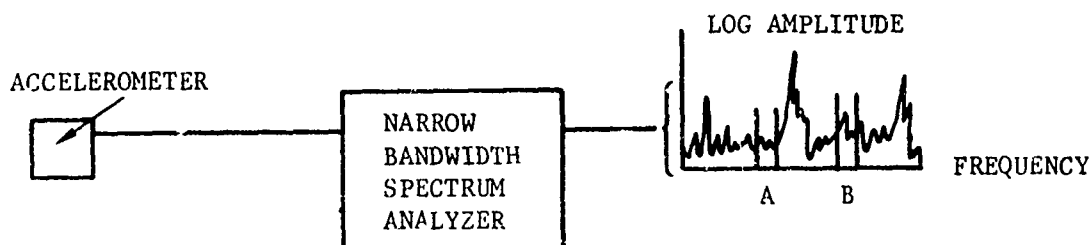


FIGURE 3-8 BLOCK DIAGRAM OF RATIO METHOD

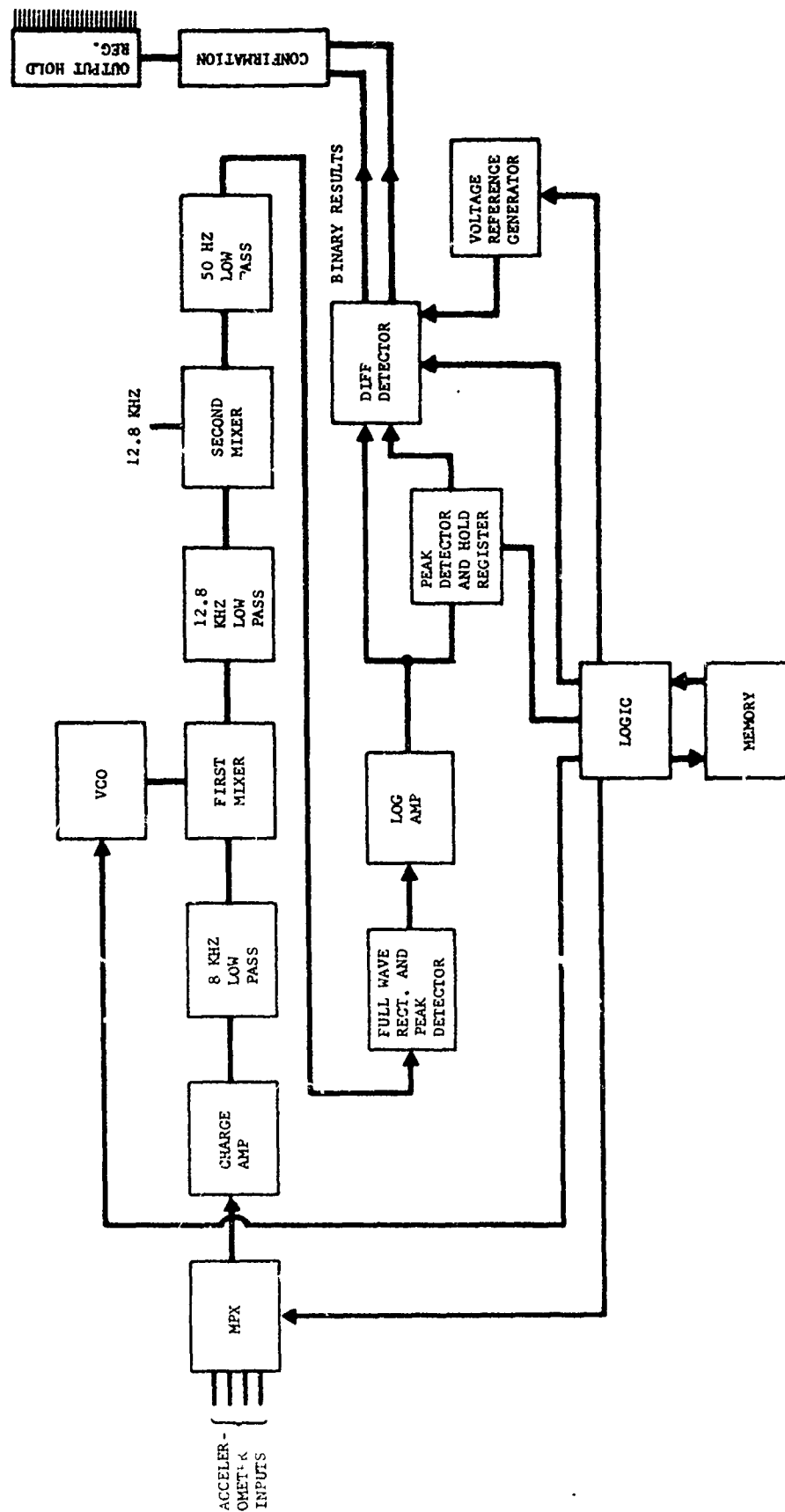


FIGURE 3-9 MRS VIBRATION MONITORING

If the ratio of peak values is greater than a programmed value, this fact is transferred into confirmation logic which allows an output if 6 out of 8 samples indicate the ratio is greater than the programmed value. A confirmed output is processed by other circuits of the EU and an output is transmitted to the CIPR for recording.

In Order for the output to change back to a state indicating the ratio is less than the programmed value, 6 out of 8 samples entered into confirmation must again indicate the ratio is less than the programmed value.

Present capability of the Vibration Spectrum Analyzer (VSA) mechanization allows the decision making process described above to yield 16 outputs, only 4 of which are presently used in the MRS. Determination of the frequency bands and levels used in the mechanization are the result of analysis of data obtained during the test bed program, particularly the early flight tests.

### 3.3.2 MRS ENGINE CALCULATOR

The MRS engine calculator has been developed to provide a simple engine performance monitoring technique. The calculator utilizes the following engine parameters and engine air properties.

- Gas producer rotor speed ( $N_1$ )
- Exhaust gas temperature (EGT)
- Engine fuel flow (WF)
- Compressor discharge pressure (CDP)
- Outside air temperature (OAT)
- Ambient air pressure (Pam)

The engine performance parameters are converted to normalized parameters to account for temperature/density effects (temperature and pressure). The following air correction factors are applied to normalize the engine parameters.

$$\text{Ambient air pressure:} \quad \delta = P_{am}/14.7$$

$$\text{Outside air temperature:} \quad \theta = \frac{OAT + 460}{519}$$

$$\text{or} \quad \theta^{.5} = \frac{(OAT + 460)^{.5}}{518}$$

Units for air pressure and temperature are in psia and °F, respectively.  
The corrected engine parameters used by the engine calculator are as follows:

Corrected engine speed,	$N_1/\sqrt{\theta}$
Corrected engine fuel flow,	$WF/\delta\sqrt{\theta}$
Corrected exhaust gas temperature,	$\frac{(EGT + 460)}{519} - 460$
Compressor pressure ratio,	(CDP/Pam)

The mechanization of the MRS engine calculator is based on the relationship of the three engine parameters ( $WF/\delta\sqrt{\theta}$ , CDP/Pam, and  $EGT/\theta$ ) as a function of corrected engine speed ( $N_1/\sqrt{\theta}$ ). The graphical plots of the engine parameters will result in linear relationships over the corrected engine speed range (85 percent to 100 percent) utilized by MRS engine calculator operation.

Equations for the engine parameters are:

$$N_1/\sqrt{\theta} = K_1 \text{ (CPR)} + K_2$$

$$N_1/\sqrt{\theta} = K_3 (WF/\delta\sqrt{\theta}) + K_4$$

$$N_1/\sqrt{\theta} = K_5 (EGT/\theta) + K_6$$

where  $K_1, K_3, K_5$  = slopes of the applicable engine parameters

$K_2, K_4, K_6$  = intercepts of the linear equations

MRS mechanized equations were derived from the preceding equations. The MRS mechanized equations are the following.

$$KCPR = \frac{1}{N_1} \left[ K_1 \sqrt{\theta} \text{ (CPR)} + K_2 \sqrt{\theta} \right]$$

$$KW_F = \frac{1}{N_1} \left[ K_3 W_F/\delta + K_4 \sqrt{\theta} \right]$$

$$KEGT = \frac{1}{N_1} \left[ K_5 (EGT)/\sqrt{\theta} + K_6 \sqrt{\theta} \right]$$

The constants for the above equations were determined from the T53-L-13 specification engine values.

Normal or abnormal engine operation can be determined from the MRS engine calculator output. A normal operating engine will present an MRS calculator output which will vary over a narrow range due to minor deviations in engine parameters from the specification values and also errors due to the sensor

circuit and electronic resolution. It will be consistent with the baseline signature data for the specific engine. Abnormal engine performance will be indicated by the deviations in the engine calculator depending on the defective part in the engine. The following examples illustrate possible MRS calculator diagnosis of an abnormal engine.

- Damaged compressor will be noted by low CPR and high EGT counts
- Degraded gas producer turbine nozzles will be indicated by low or high CPR counts and low or high EGT counts depending on the nozzle damage mode (increase or decrease in nozzle area)
- Discrepant power turbine will be indicated by high fuel flow counts and irregular EGT counts

Predetermined levels of calculator abnormal are incorporated in EU limit detection circuits. Occurrence of abnormals (level exceedance) causes outputs to be transmitted to the CIPR. Outputs of calculator abnormals are, however, transmitted only if certain stability conditions exist which insure the validity of the calculation.

The mechanization of the calculator is quite straight forward. Basic mathematical functions are used to form the factors in the equations for KCPR,  $KW_F$ , and KEGT stated previously. These functions are multipliers, dividers, adders, and scalers which are mechanized by digital to analog converters, analog to digital converters, and operational amplifiers. In order to minimize the hardware impact, linear approximations are used where appropriate. As an example, Figure 3-10 illustrates a KCPR calculator output function. The term "to" is the standard day temperature in degrees absolute.

#### Other Monitoring

Many other monitoring functions are mechanized by the MRS (see Table 3.1).

Figures 3-11 and 3-12 present examples. They are typical monitoring examples of aircraft parameters other than vibration and engine health. In each case, one or more inputs are sampled and processed by decision making circuits of the EU. Before EU status memory is allowed to change or outputs be transmitted to

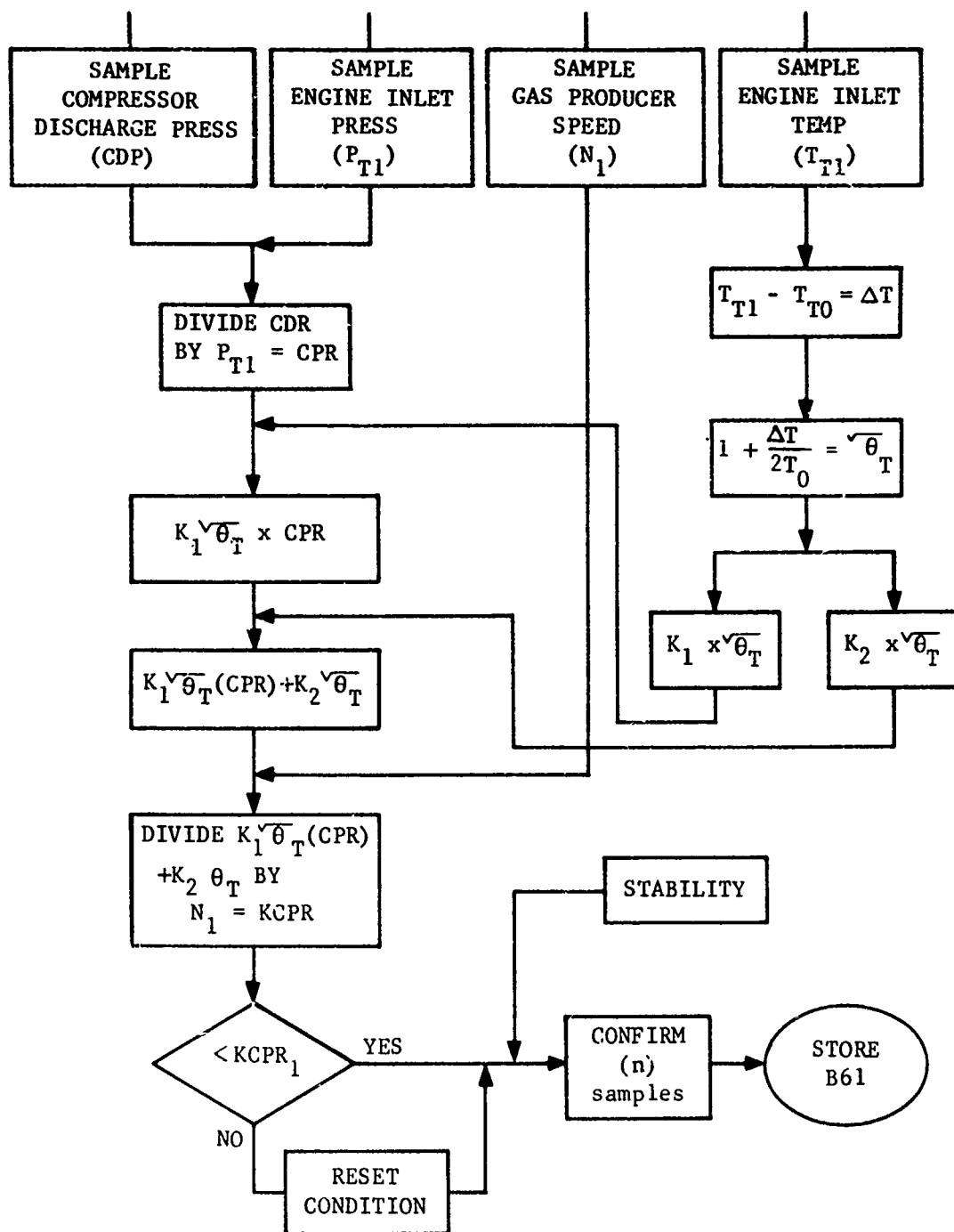


FIGURE 3-10 KCPR CALCULATIONS

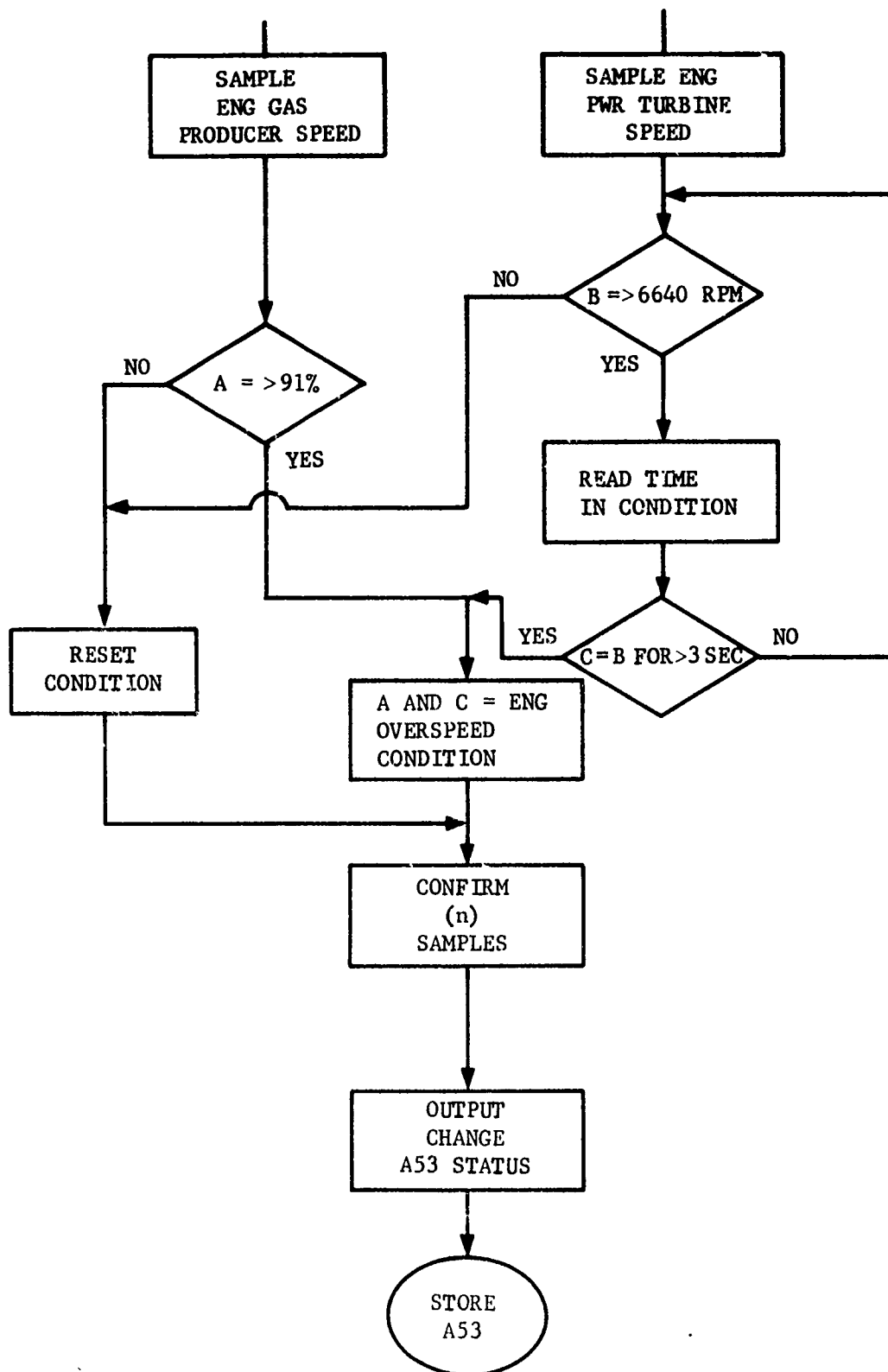


FIGURE 3-11 ENGINE OVERSPEED

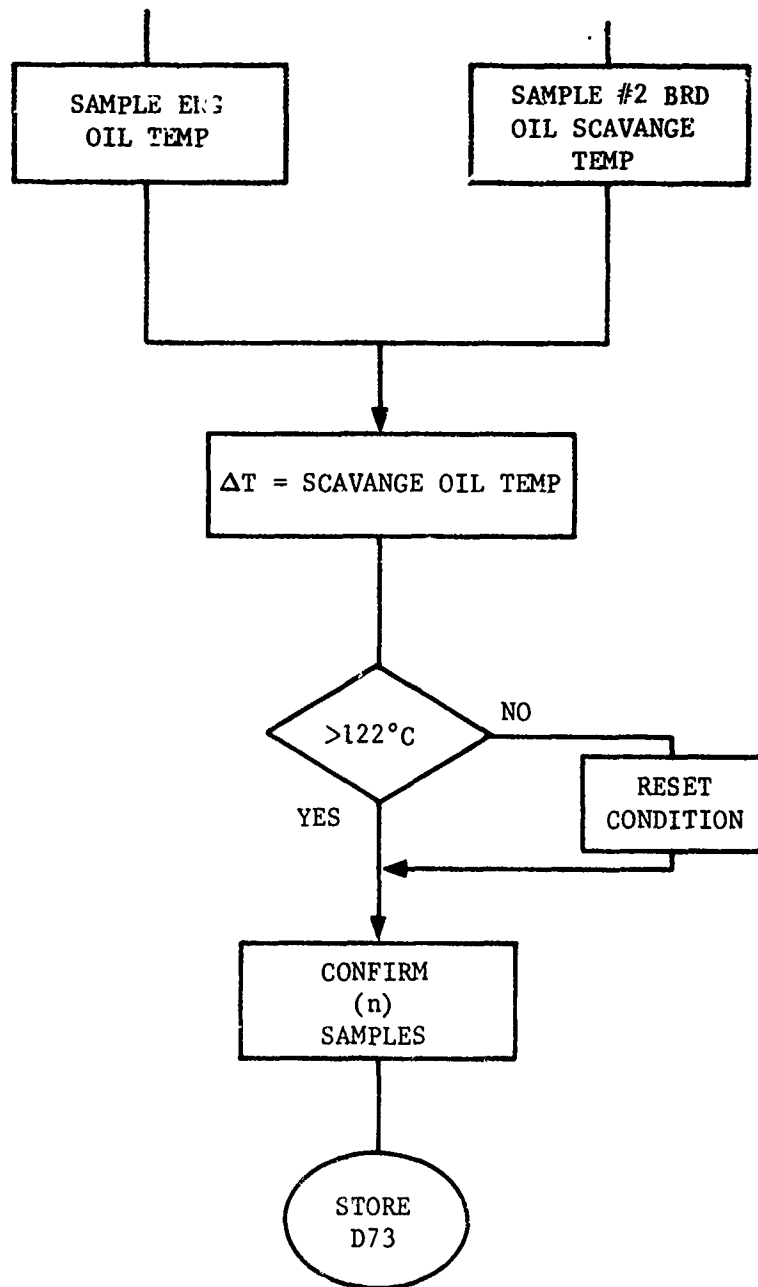


FIGURE 3-12 NO. 2 BEARING OIL DIFFERENTIAL TEMPERATURE

the CIPR for storage, a confirmation process must be satisfied. The confirmation process minimizes changes in output status and reduces the transient effects of parameters.

### 3.3.3 MAINTENANCE DATA STORAGE

The Continuous Inflight Performance Recorder (CIPR) provides the airborne data storage capability for the MRS. CIPR is composed of two subassemblies, a controller and a magazine, which have the capability of four data channels. The four channels, as used on the test bed program, are

- Maintenance data
- Engineering quantitative data
- Audio
- Time

The controller accepts codified data from the EU and in conjunction with control signals, records the data on the magnetic tape of the magazine (see Figure 3-13). Circuits of the controller provide drive power for the tape mechanism, sensing circuits for direction control, magnetic head selection circuits, data conditioners, and record circuits. In addition, circuits within the controller detect circuit and drive failures.

When a maintenance condition has been detected by the EU, a control signal commands the controller to drive. After outputs from speed sensing circuits in the controller are satisfactory, the EU transmits the codified maintenance data to the controller. Level adjustments are then made by the controller and the data is recorded directly on the magnetic tape of the magazine.

The magazine is essentially a gear-driven type of magnetic tape cartridge which has self-contained magnetic heads. Storage capacity is maximized by eight data tracks on the 1/4-inch tape. Automatic reversing uses four tracks in one direction and four tracks in the opposite direction.

### 3.3.4 MAINTENANCE DATA RECOVERY

At the completion of a flight, the CIPR magazine is removed from the aircraft and connected to the DRU. Placing DRU switches and controls to the correct position initiates a rapid rewind and allows data stored to be recovered by playing the magazine at normal speed.

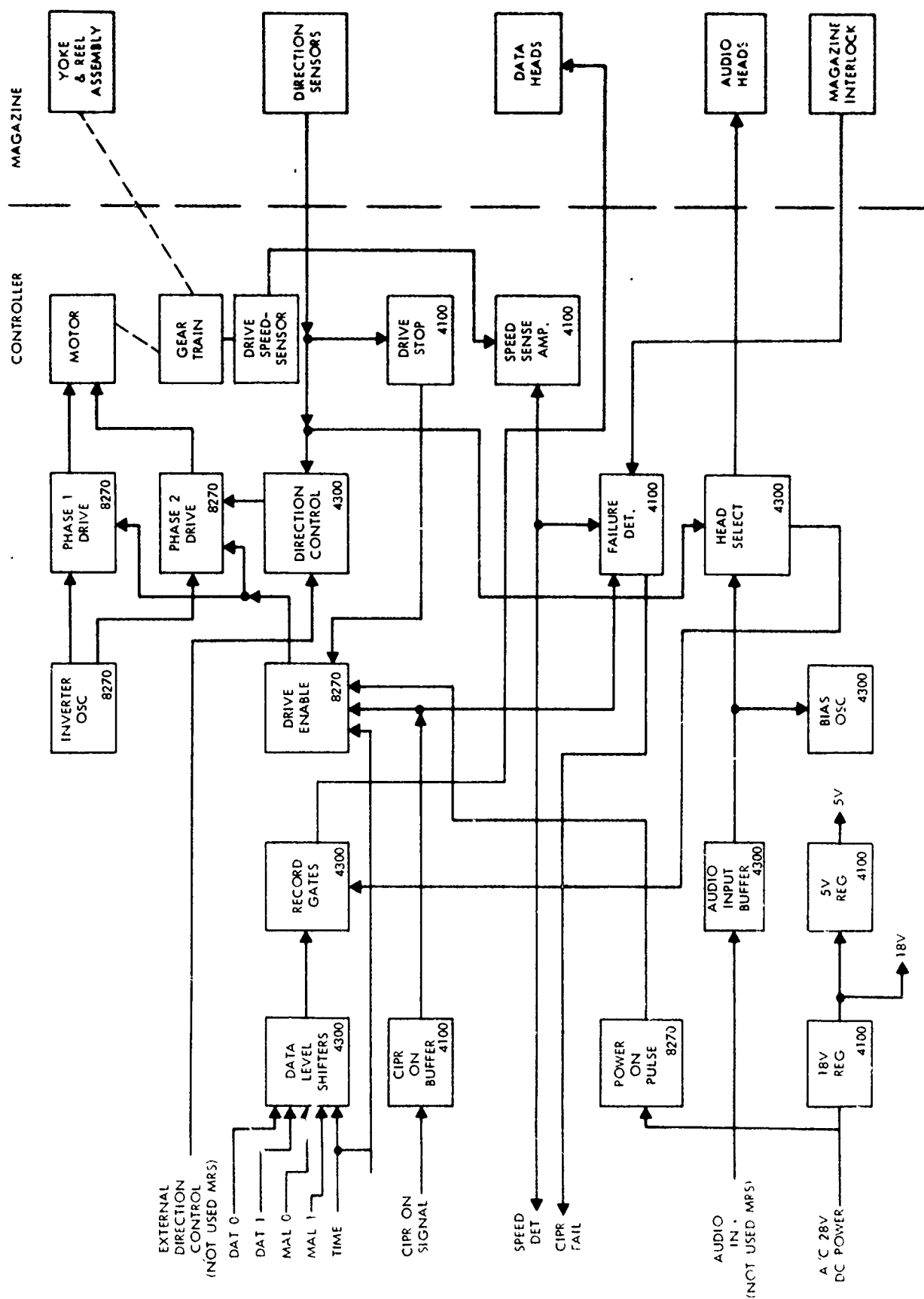


FIGURE 3-13 CIPR FUNCTIONAL BLOCK DIAGRAM

When data from the main channel (alpha numeric maintenance data) is selected for playback, data from the magnetic tape enters the DRU, as shown in the block diagrams of Figure 3-14. Synchronization is obtained by recognizing a definite structure of the input code words and errors are detected by checking parity codes, bit positions, and the absence of pulses. The data is decoded and converted to BCD for each of the assigned columns of the printer. Maintenance data is printed on the first three columns. Time, which is counted concurrent with the playback, is printed on the last four columns (see example in Section 3.1). A plus sign is printed in the fourth column when a code occurs and a minus sign when the condition returns to normal. A period is normally printed in the fifth column except when an error is detected and an "A" is printed.

When data from the engineering channel is selected, data is handled in the same manner as the main channel except that a special code (K11), which precedes the engineering data, is decoded and conversion to a binary count representing analog values is printed in the last three columns (see example in Section 3.1). The first four columns print periods and columns five and six identify the data channel (01 through 19) and column seven prints a dash. K11 + and time is printed at the start of the engineering data and K11 - and time is printed at the end. Pre-established correlation of the binary count of columns eight, nine, and ten to the analog value of the parameter assigned to a particular data channel determines the value of the parameter at the time of the sample.

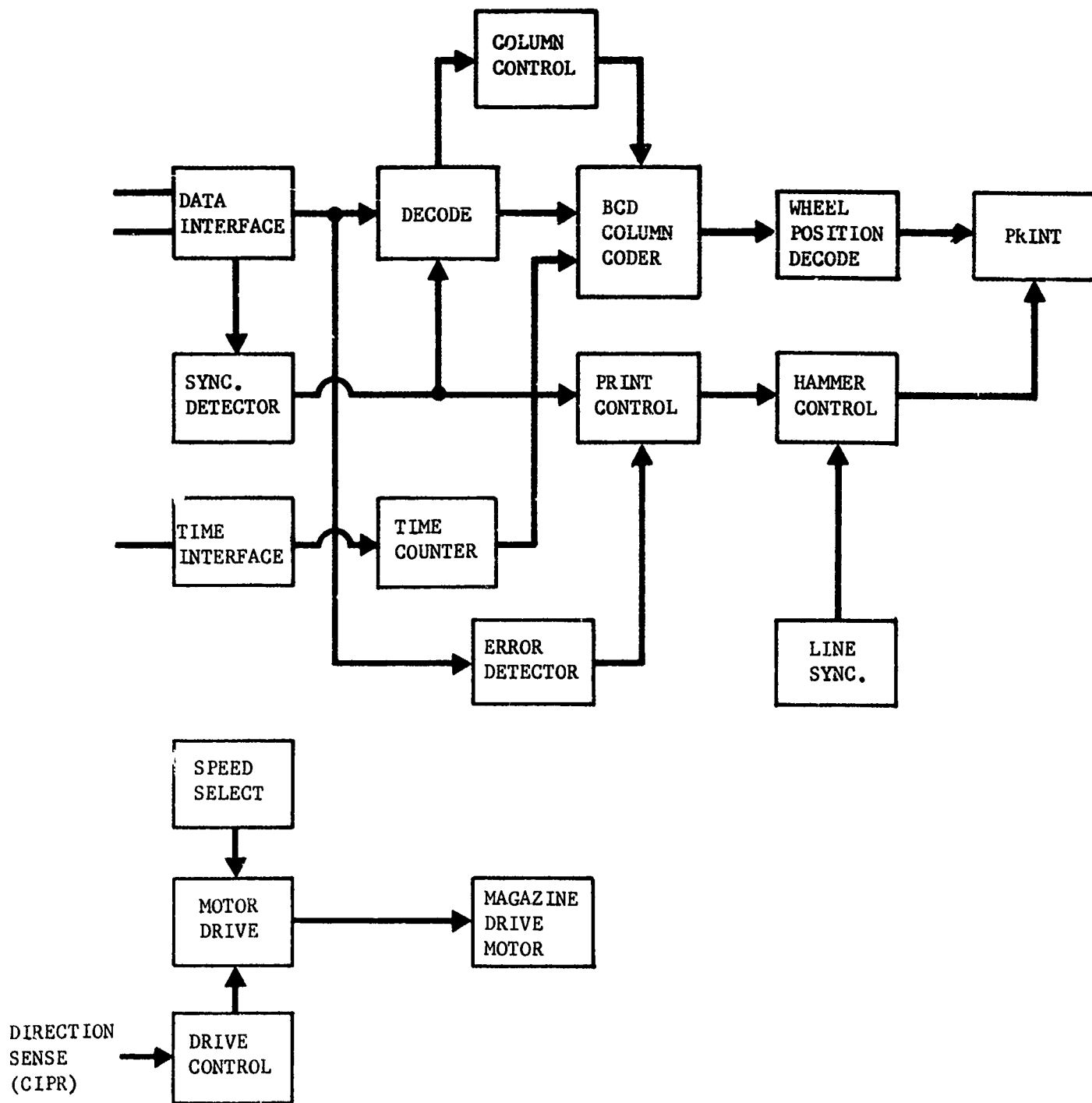


FIGURE 3-14 DRU BLOCK DIAGRAM

## SECTION 4

## 4.0 PREPARATION FOR TEST CELL PHASE

### 4.1 GENERAL

The test cell preparation phase encompassed all the planning, hardware definition, parameter selection, and Army approval actions incident to instrumentation of UH-1 engine, main transmission, 42 and 90 degree gear box test cells, located at ARADMAC. A significant ground rule imposed by the Army was that instrumentation of the cells would be accomplished on a noninterference (ARADMAC production schedule) basis. This constraint dictated the accomplishment of cell instrumentation at night, and during weekends.

### 4.2 OBJECTIVES

The two primary objectives of this phase were:

1. To define and finalize all MRS hardware elements required to support the test cell operation, and insure compatibility with the follow-on flight test phase.
2. To prepare and secure Army approval of MRS installation data and instructions for instrumentation of the test cells and aircraft.

### 4.3 HARDWARE DETERMINATION

The process of hardware determination for the test cells was accomplished with constant consideration to the required interface with the flight test phase. This approach obviated potential compatibility (cell vs aircraft) problems downstream in the test bed program.

#### 4.3.1 ANCILLARY TASKS

In arriving at the final hardware configuration, several related tasks were accomplished and are summarized below.

##### 4.3.1.1 Data Review

A comprehensive review of Army helicopter operational and logistical data, available in the Northrop data bank, and augmented from Army sources, was accomplished. These data were synthesized and used in finalizing

parameter lists, sensor selection, signal source analysis and general equipment functional performance requirements for diagnostic and prognostic component analysis. During the parameter and sensor selection activity, emphasis was placed on the relationship between the parameters and their relative value in performing component inspection and/or malfunction diagnosis and prognosis. Included within the diagnostic and prognostic aspects of the problem was the requirement to isolate critical items: those requiring frequent maintenance, those requiring extensive time to isolate, those of high dollar value, and those critical to mission accomplishment.

#### 4.3.1.2 Test Cell Survey

The second task in the test cell preparation phase entailed an on-site survey at ARADMAC of engine, main transmission, 42 and 90 degree gear box test cells. Northrop was assigned specific cells for the entire test phase. Detailed measurements and interface requirements between the MRS and test cell equipment were obtained/determined during the survey. A significant finding from the survey was that wiring, mounts, harness, etc., could be prefabricated with wire bundle lengths precut and ready for quick installation in the cells.

#### 4.3.1.3 Adaptation Requirements

Analysis of the data previously discussed, coupled with the test cell installation factors from the field survey, facilitated adaptation requirements for the MRS. Thus it was possible to prefabricate MRS and sensor bracketry, precut and bundle wiring and harness, and finalize the overall MRS configuration prior to entering the test cell instrumentation phase of the test bed program.

#### 4.4 SENSOR CALIBRATION

The planning phase for sensor calibration addressed three specific areas. First, Northrop selected sensors from vendors recognized in their individual fields for quality components; i.e., Endeco Accelerometers and Foxboro Fuel Flow Meters. These sensors were then furnished by the vendors with certified calibration standards. Secondly, Army calibration standards and (30-day) calibration values were obtained from ARADMAC for the test cells assigned to

Northrop for the test bed program. Thirdly, arrangements were concluded with ARADMAC to accomplish a verification calibration subsequent to instrumentation of the test cells.

In view of the importance of calibration in ensuring the validity of the MRS test bed results, planning and coordination was accomplished with ARADMAC to obtain a waiver on the Standard Operating Procedure (SOP) 30-day calibration cycle, and additional calibration checks were accomplished during the test phase.

#### 4.5 ACCOMPLISHMENTS

In summary, the objectives outlined for the Preparation for Test Cell Phase were accomplished. Specifically, MRS definition and finalization, including system testing, was completed to the level that permitted instrumentation of the test cells without major impact on ARADMAC operations. Details of the instrumentation phase are addressed in Section 5.0. Secondly, the total MRS installation package, as submitted by Northrop, was subsequently approved without change by the proponent Army agency (Aviation Systems Command).

## **SECTION 5**

## 5.0 TEST CELL PHASE

### 5.1 OBJECTIVES

The basic objectives of the test cell phase of the program were to:

- 1) Develop a data base of UH-1H serviceable and degraded component performance and parameter signatures.
- 2) Ensure the successful integration and operation of the Maintenance Reporting System (MRS) in the UH-1H test bed aircraft.

### 5.2 TEST CONDUCT

The test cell phase was accomplished during the period 23 October 1970 through 2 December 1971. Three separate test cells were utilized including an engine cell, a main transmission cell, and a combined 42/90 degree gearbox cell.

#### 5.2.1 ENGINE TEST CELL

Test conducted in the engine cell included baseline runs of no defect engines, runs with implanted discrepant parts, and baseline reruns of no defect engines. Details of the operation are presented in paragraph 5.3.

#### 5.2.2 MAIN TRANSMISSION TEST CELL

Tests of main transmissions included baseline no-defect runs, discrepant parts implant, high time transmissions removed per TBO criteria, and rerun no-defect baseline runs.

#### 5.2.3 42/90 DEGREE GEARBOX TEST CELL

Testing of UH-1H gearboxes at ARADMAC is accomplished in a common test cell which simulates the drive train of the aircraft. Tests of gearboxes followed the same general sequence as main transmissions, that is, baseline no-defect, high time boxes removed per TBO criteria, discrepant parts implant, and rerun no-defect runs.

### 5.3 INSTRUMENTATION

#### 5.3.1 ENGINE TEST CELL

Figure 5-1 contains a block diagram of the Northrop Engine test cell instrumentation. Table 5.1 itemizes each parameter and its associated sensor. All engine instrumentation in the test cell was planned to duplicate the subsequent aircraft installation as much as possible. In order to duplicate the aircraft instrumentation, a UH-1H aircraft torque and oil pressure meter was installed in the test cell to properly load the corresponding transmitter on the engine. However, due to the engine configuration peculiar to the test cell not all signals or sensors were available. For instance, special test cell fuel and oil supply systems existed and most of the aircraft fuel and oil system sensors and signals were not available.

Since many of the engine sensors were also being monitored by ARADMAC, tests were made to verify that ARADMAC readouts were not being degraded by Northrop's instrumentation. In addition, the added precaution was taken after each Northrop engine run to disconnect all Northrop instrumentation from the basic test cell wiring.

The conditioning of the engine transducer signals was done in the MRS. In addition, three frequency signals, i.e., N<sub>1</sub> speed, N<sub>2</sub> speed, and fuel flow, were converted to D.C. before being recorded on an oscillograph.

#### 5.3.2 TRANSMISSION TEST CELL

Figure 5-2 presents a block diagram of the Northrop transmission test cell instrumentation. Vibration signals were the only parameter instrumented by Northrop. Transmission oil temperature was recorded off the existing cell instrument. Four piezoelectric accelerometers were used. The location and brackets were identical to the subsequent aircraft installation. Two accelerometers were permanently located (lateral case and normal mast), and two were designated as roving accelerometers. Their location was determined by the closest proximity to the particular discrepant part under test. For instance, if the discrepant was an input quill, the two roving accelerometers were placed near the input quill in the normal and longitudinal directions. The vibration signals were conditioned by charge converters. Figure 5-3 illustrates the installation of the accelerometers in the transmission test cell.

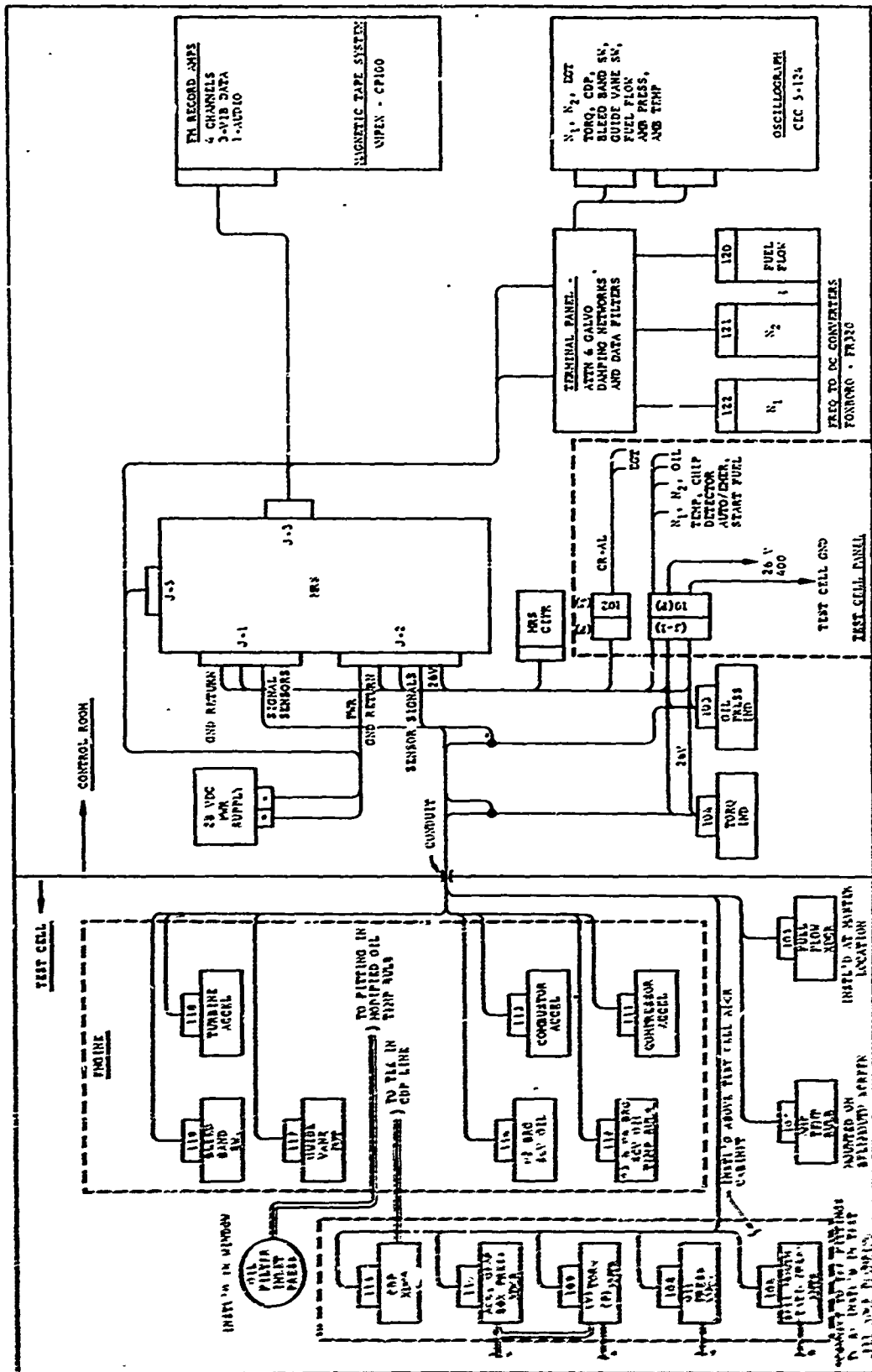


FIGURE 5-1 ENGINE TEST CELL INSTRUMENTATION

TABLE 5.1 ENGINE TEST CELL PARAMETER

PARAMETER	SENSOR	SENSOR USAGE	SIGNAL CONDITIONER	DATA USAGE
N <sub>1</sub> Speed	Engine N <sub>1</sub> Tachometer Generator	Northrop/ARADMAC	MRS and Frequency to DC Converter	Oscillograph/MRS
N <sub>2</sub> Speed	Engine N <sub>2</sub> Tachometer Generator	Northrop/ARADMAC	MRS and Frequency to DC Converter	Oscillograph/MRS
Exhaust Gas Temp (KOT)	Engine KOT Probes Alumel/Chromel	Northrop/ARADMAC	MRS	Oscillograph/MRS
Torque	Engine Torque Transmitter With Aircraft Torque Meter	Northrop	MRS	Oscillograph/MRS
Compressor Discharge Pressure (GDP)	Statham PA 208TC-100-350 Strain Gage Bridge	Northrop	MRS	
Engine Oil Temperature	Engine Oil Temperature Sensor	Northrop/ARADMAC	MRS	MRS
Engine Chips	Engine Chip Detector	Northrop/ARADMAC	MRS	MRS
Bleed Band Position	Microswitch	Northrop	MRS	Oscillograph/MRS
Inlet Guide Vane Position (IGV)	GIC 70 10NCT Potentiometer	Northrop	MRS	Oscillograph/MRS
Fuel Governor Auto/Emerg. Switch	Test Cell Switch	Northrop/ARADMAC	MRS	MRS
Starting Fuel Switch	Test Cell Switch	Northrop/ARADMAC	MRS	MRS
Fuel Flow	Foxboro 1/2"-2-81-200 Flow Transmitter	Northrop	MRS and Frequency to DC Converter	Oscillograph/MRS
Ambient Pressure (Pam)	Statham PA208TC-15-350 Strain Gage Bridge	Northrop	MRS	Oscillograph/MRS
Ambient Temperature (T-am)	Lewis 5401 Temp. Probe	Northrop	MRS	Oscillograph/MRS
Necessary Gearbox Pressure	GKC 4-312-3PSI	Northrop	MRS	MRS
No. 2 Bearing Scavenge Oil Temp.	Lewis 50017C NS20034-3 Temp. Probe	Northrop	MRS	MRS
No. 3 & 4 Bearing Scavenge Oil Temp.	Lewis 50017C NS20034-3 Temp. Probe	Northrop	MRS	MRS
Compressor Vibration	Kndevco 6222-M2 Piezoelectric Accelerometer	Northrop	MRS	MRS/Tape Recorder
Combustor Vibration	Kndevco 6222-M2 Piezoelectric Accelerometer	Northrop	MRS	MRS/Tape Recorder
Turbine Vibration	Kndevco 6222-M2 Piezoelectric Accelerometer	Northrop	MRS	MRS/Tape Recorder

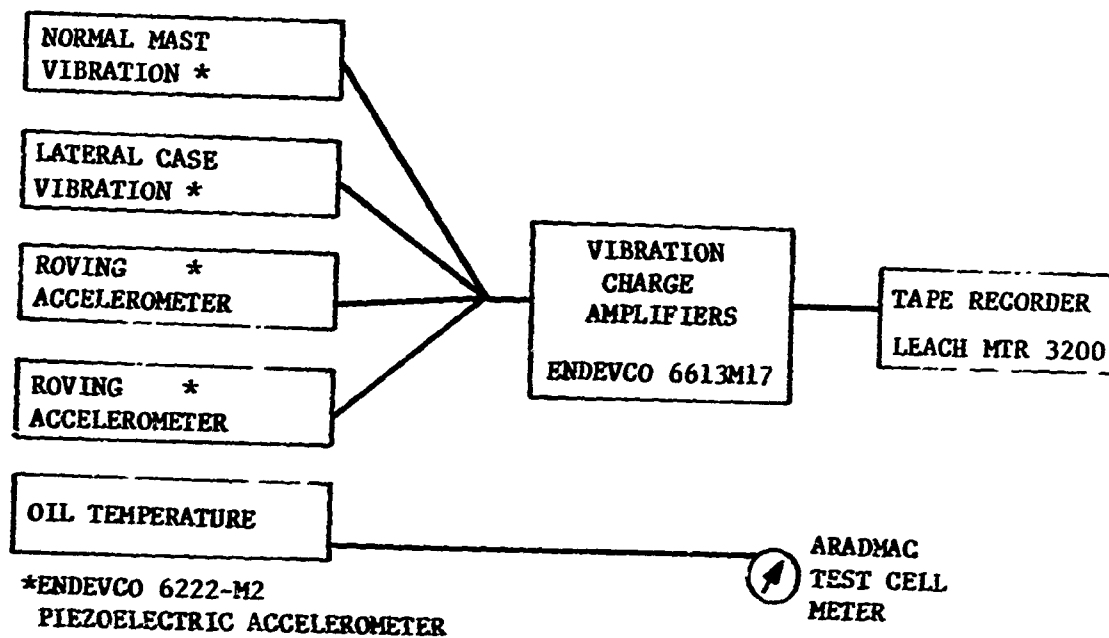


FIGURE 5-2 TRANSMISSION TEST CELL INSTRUMENTATION BLOCK DIAGRAM

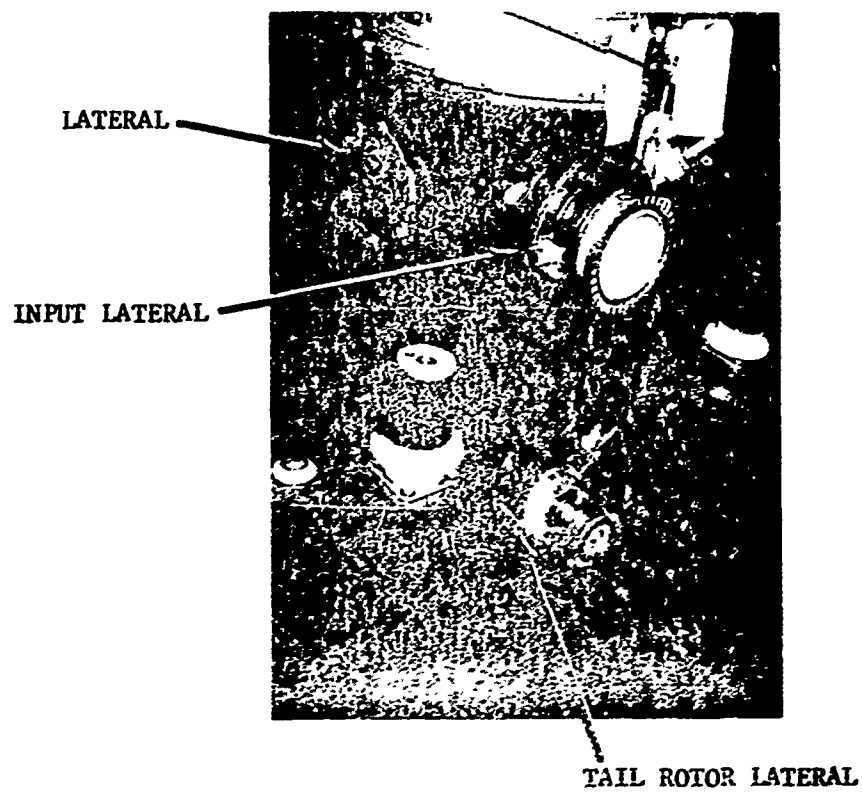


FIGURE 5-3 TRANSMISSION TEST CELL INSTRUMENTATION

### 5.3.3 GEARBOX TEST CELL

Figure 5-4 contains the gearbox test cell instrumentation block diagram. Two piezoelectric accelerometers were mounted on each gearbox in the same manner as in the subsequent aircraft installation. On the 90° gearbox the accelerometers sensed lateral and normal vibrations. The two on the 42° gearbox sensed longitudinal and normal vibrations. The vibration signal from the piezoelectric accelerometers was conditioned by charge amplifiers. In addition, two temperature sensors were employed for each gearbox, one for the internal oil temperature and another for the external gearbox temperature. Illustrations of the accelerometer and temperature sensor installations in the gearbox test cell appear in Figure 5-5.

## 5.4 DATA ACQUISITION

### 5.4.1 ENGINE TEST CELL

Engine performance data was recorded in the engine test cell from Northrop instrumentation on a magnetic tape recorder, oscillograph, and MRS recorder (CIPR). In addition, data was also recorded manually from ARADMAC test cell instruments both by Northrop and ARADMAC personnel. All Northrop installed vibration sensor signals were recorded on an Ampex CP100 FM instrumentation tape recorder. Continued traces of basic engine parameters were recorded on a CEC 5-124 oscillograph. Data collection assignments are shown in Table 5.2. The MRS recorded that data applicable to the engine test stand operation in addition to exceedance of limit signals. Parameters recorded by the MRS recorder were  $N_1$  speed,  $N_2$  speed, EGT, torque pressure, compressor pressure, ambient temperature, and ambient temperature. A copy of the ARADMAC run sheet was retained for each engine test. In addition, Northrop manually recorded on its data sheet the values of  $N_1$  speed,  $N_2$  speed, IGV position, torque pressure, and engine oil filter input and output pressures from test cell instruments.

### 5.4.2 TRANSMISSION AND GEARBOX TEST CELL

Data acquisition in both the transmission and gearbox test cells were similar. Vibration signals from Northrop accelerometers were recorded on a Leach MTR3200 FM instrumentation tape recorder. In addition, temperature data was recorded

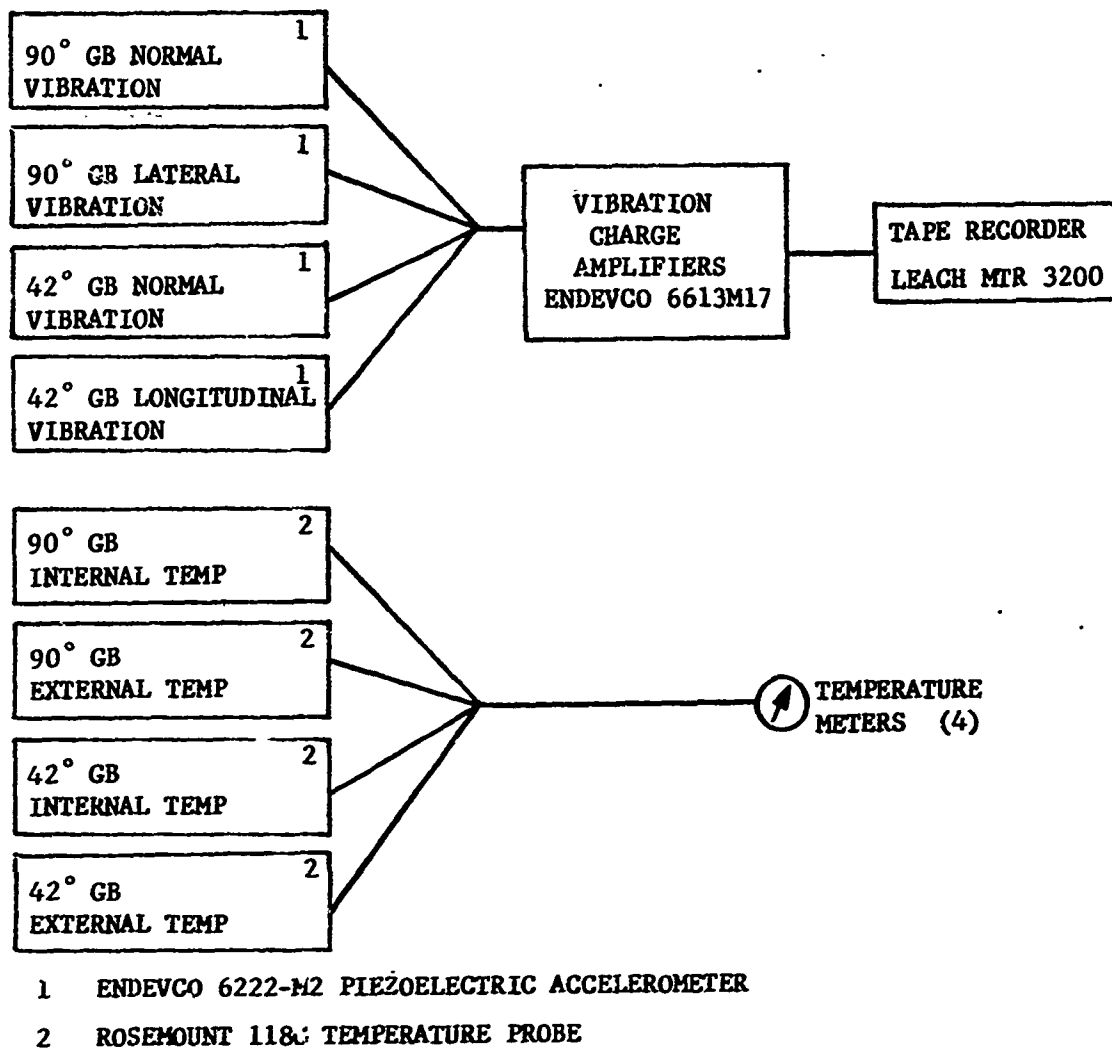


FIGURE 5-4 GEARBOX TEST CELL INSTRUMENTATION BLOCK DIAGRAM

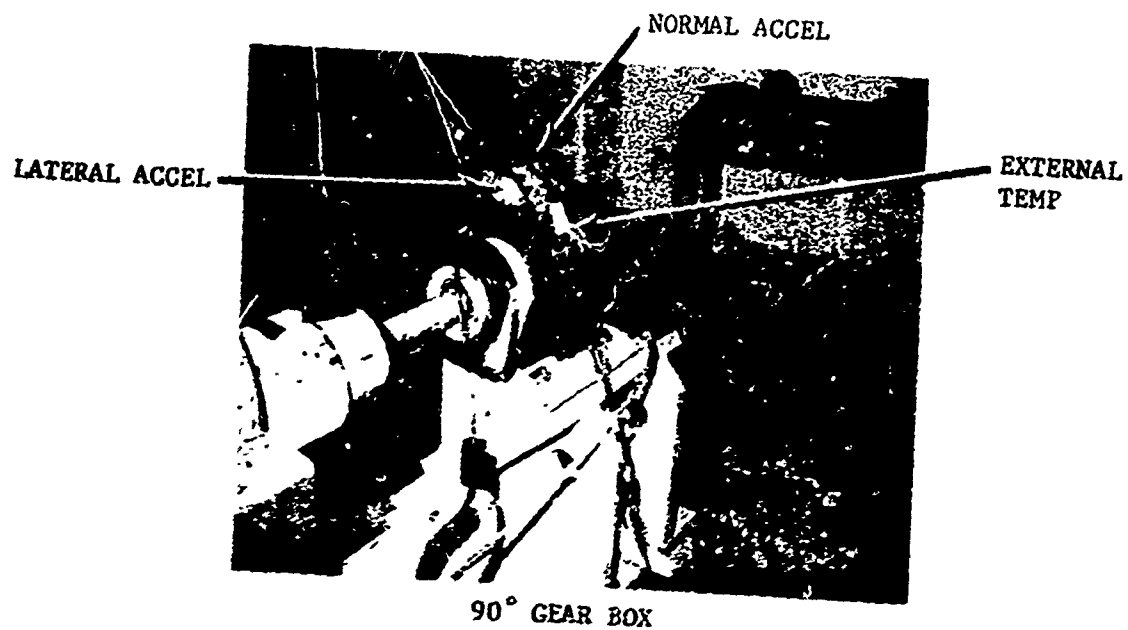
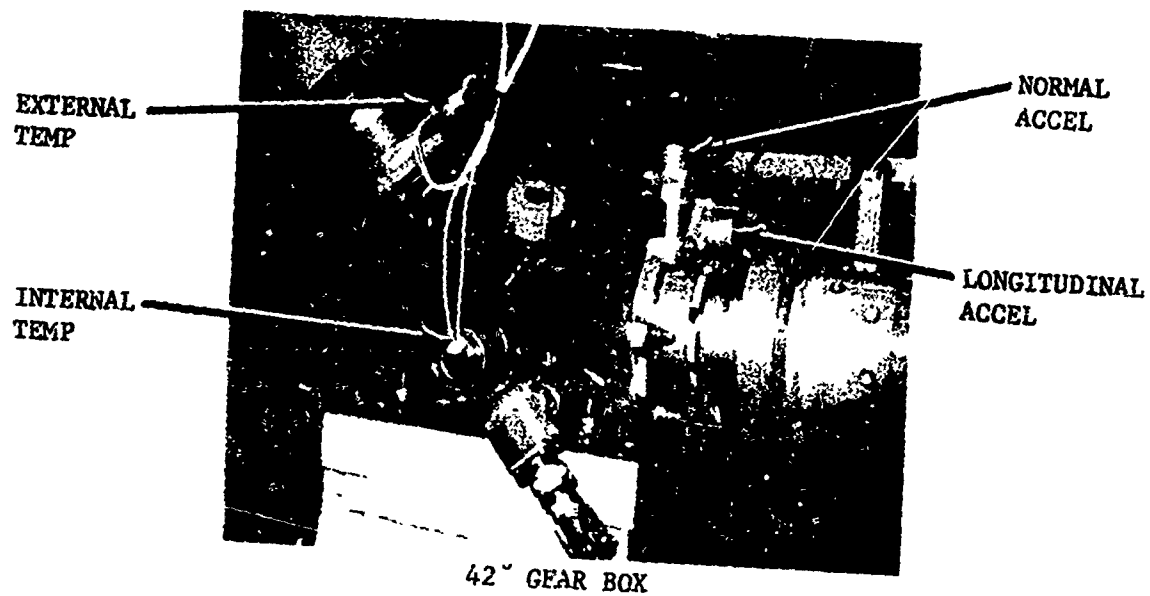


FIGURE 5-5 GEARBOX TEST CELL INSTRUMENTATION

TABLE 5.2 ENGINE DATA RECORDINGS  
(TAPE RECORDER AND OSCILLOGRAPH)

<u>RUN NO.</u>	<u>DATA REQUIRED*</u>	<u>RUN CONDITION</u>
1	O,T	ENGINE OFF
2	O	START TO IDLE
3	O,R,M	GROUND IDLE (G.I.)
4	O,R,M	FLIGHT AUTOROTATION (F.A.)
5	R	INLET GUIDE VANE CHECK (IGV)
6	R	BLEED BAND CHECK
7	R	VIBRATION $N_1$ - 65%, $N_2$ - 50%
8	R	VIBRATION 70 60
9	T,R	VIBRATION 75
10	R	VIBRATION 80 80
11	T,R	VIBRATION 85 97.3
12	T,R	VIBRATION 90 94.8
13	T,R	VIBRATION 90 97.3
14	T,R	VIBRATION 90 100.4
15	T,R	VIBRATION 95 97.3
16	R	FUEL FLOW VS. MANIFOLD PRESSURE CHECK
17	R	OVERSPEED GOVERNOR CHECK (OSG)
18	O,R,M	F.A.
19	C,O,T,R,M	MILITARY RATED POWER (MRP)
20	C,O,T,R,M	75% NORMAL RATED POWER (NRP), $N_2$ - 97% TO 100%
21	C,O,T,R,M	NRP, $N_2$ - 97% TO 100%
22	C,O,T,R,M	FLIGHT IDLE, $N_1$ - 70% TO 72%, $N_2$ - 62% APPROX.
23	O	FLIGHT IDLE TO NRP SLOW ACCEL.
24	O	NRP TO FLIGHT IDLE SLOW DECEL.
25	O,R	NRP, $N_2$ - 97% TO 100%
26	O	FLIGHT IDLE, $N_1$ - 70% TO 72%, $N_2$ - 65% APPROX.
27	C,O	COAST DOWN (FROM FLIGHT IDLE)
28	O,T	ENGINE OFF

\*O Oscillograph  
T Tape Recorder  
R Run Sheet (ARADMAC)  
C CIPR (MRS Recorder)  
M Manual Recordings (Northrop)

manually on Northrop data sheets. In the transmission test cell, oil temperature was recorded from the ARADMAC test cell meter. In the gearbox test cell, internal oil temperature and external case temperatures were recorded from Northrop temperature meters. In addition, internal gearbox oil temperatures were recorded from ARADMAC test cell meters.

## 5.5 TEST CONDITIONS

### 5.5.1 ENGINE TEST CELL

Engine run conditions are also stated in Table 5.2. In addition, this table specifies the data modes at each step. The method of testing engines was basically the same as that which was called out in ARADMAC Work Requirement Manual WR 55-2840-113. After a ground and flight idle check, an IGV and bleed band check and a vibration check, steady state data points were recorded. A steady state point was set as follows:

- 1) A power lever position (PLP) was selected.
- 2) N<sub>2</sub> RPM was set to the optimum value based on power required and ambient temperature.
- 3) Engine was allowed to stabilize at the power setting until all parameters were steady. Data was then recorded.

### 5.5.2 TRANSMISSION AND GEARBOX TESTS

Abbreviated ARADMAC test cell run procedures were adapted as a basis of the tests in the transmission and gearbox test cells. Six test conditions were established in the transmission test cell and nine in the gearbox test cell.

Table 5.3 details the operation in each cell.

## 5.6 TEST SPECIMENS

### 5.6.1 ENGINE

Table 5.4 summarizes the engine test schedule and engine configuration. Ten ARADMAC overhauled engines were run through test cell #13. After production engine signature data was collected, a group of four engines, designated as the diagnostic engines, were implanted with a series of defective parts and retested in order to

TABLE 5.3

## TRANSMISSION TEST CELL - TEST CONDITIONS

<u>STEP</u>	<u>INPUT RPM</u>	<u>MAST LOAD %*</u>	<u>T/R LOAD</u>	<u>GEN AMPS</u>
1	5800	17	Low	150
2	6200	58	Low	150
3	6600	74	Low	150
4	7040	90	Low	150
5	660	138	Low	200
6	6600	128	High	200

\*100% = 150,000 in lbs.

## GEARBOX TEST CELL - TEST CONDITIONS

<u>STEP</u>	<u>90° SHAFT OUTPUT RPM</u>	<u>EQUIVALENT ENGINE RPM</u>	<u>90° OUTPUT TORQUE IN-LBS</u>
1	0	0	0
2	1100	4381	1430
3	1300	5178	1170
4	1454	5791	1835
5	1454	5791	2470
6	1604	6389	2210
7	1765	7030	2210
8	1605	6389	3640
9	1604	6389	1170

**TABLE 5-4**  
**PARTS OPERATED IN TEST CELL**  
**T53-L-13A ENGINE RUN SUMMARY**

ENGINE NUMBER	DATE RUN	DESCRIPTION OF ENGINE	COMMENTS
LE14400	10-12	ARADMAC Vib. Engine	Special ARADMAC Vib. Engine
LE20998	10-14	Production	Rerun on 10-16
LE17865	10-15	Production	
LE20998	10-16	Production Rerun	
LE16614	10-16	Production	
LE16746	10-19	Production	Rejected for high No. 3 vibration
LE14255	10-20	Production	
LE15165	10-21	#1 Diagnostic Baseline	
LE20727	10-22	#2 Diagnostic Baseline	
LE15351	10-23	#3 Diagnostic Baseline	
LE15165	10-26	Bad #2 Bearing	Cell instrumentation limits not exceeded
LE20767	10-27	Bad #3 Bearing	Cell instrumentation limits not exceeded
LE15351	10-28	Bad #4 Bearing	Indication on cell instrumentation that No. 4 Bearing was bad only at low speed
LE15165	10-30	Bad #2 Bearing	No indication on cell instrumentation that No. 3 Bearing was bad
LE20727	11-2	Bad #3 Bearing	MRS in system, all data uncalibrated minor FOD to engine compressor, 2 nicks first stage, 1 nick second stage
LE15351	11-3	Bad #4 Bearing	
LE18993	11-4	Bad N1 Nozzles	

TABLE 5-4 (Continued)  
PARTS OPERATED IN TEST CELL  
T53-L-13A ENGINE RUN SUMMARY

ENGINE NUMBER	DATE RUN	DESCRIPTION OF ENGINE	COMMENTS
LE15665	11-5	Bad #2 Bearing	Nozzles burned, warped, minor FOD
LE20727	11-6	Bad #3 Bearing	
LE15351	11-9	Bad #4 Bearing	
LE18993	11-10	Bad N <sub>1</sub> Nozzles	
LE15165	11-12	Bad #2 Bearing	
LE15351	11-13	No Defects	Fuel Control misrigged, IGV's misrigged
LE18993	11-16	Bad N <sub>2</sub> Nozzles	Noisy (audio) engine
LE20727	11-17	Bad Power Turbine	
LE18993	11-18	Bad N <sub>2</sub> Nozzles	
LE15165	11-19	Degraded Compressor	
LE20727	11-20	Bad Power Turbine	
LE15351	11-20	#3 Diagnostic Baseline	Data shows overlimit vibs at power turbine at 80% N <sub>1</sub>
LE18993	11-23	#4 Diagnostic Baseline	
LE20727	11-24	#2 Diagnostic Baseline	
LE15615	11-24	Bad Compressor	

establish unique signatures of selected defective parts. Subsequently, the diagnostic engines were restored to their original condition and again run through the test cell. A total of 32 engine runs were made.

Defective engine parts were limited to the following items:

- a) #2 bearings (4)
- b) #3 bearings (3)
- c) #4 bearings (3)
- d)  $N_1$  nozzles (2)
- e)  $N_2$  nozzles (2)
- f) Compressors (2)
- g) Power turbines (2)

Figure 5-6 illustrates a discrepant compressor.

#### 5.6.2 TRANSMISSIONS AND GEARBOXES

Tables 5.5 and 5.6 summarize the test cell transmission and gearbox testing, respectively. Test sequence and discrepant serialization and qualitative descriptions are included. A group of four overhauled units of each type were used throughout these tests. Initially, each unit was tested with no known defects (out of overhaul). Then a series of runs were made with a defective component implanted. Final tests in the test cells were conducted with the units back in their original overhauled condition. In addition, four high time units were run in the cells, once at the beginning and after being overhauled, prior to the conclusion of the test cell phase. The defective parts used in the transmission test cell are listed below.

- a) Main mast bearings (6)
- b) Input quill bearings (tryplex) (10)
- c) Tail rotor output bearings (ball and roller) (11)
- d) Upper sun gear (3)
- e) Upper and lower planetary gears (5)
- f) Accessory drive gears (4)

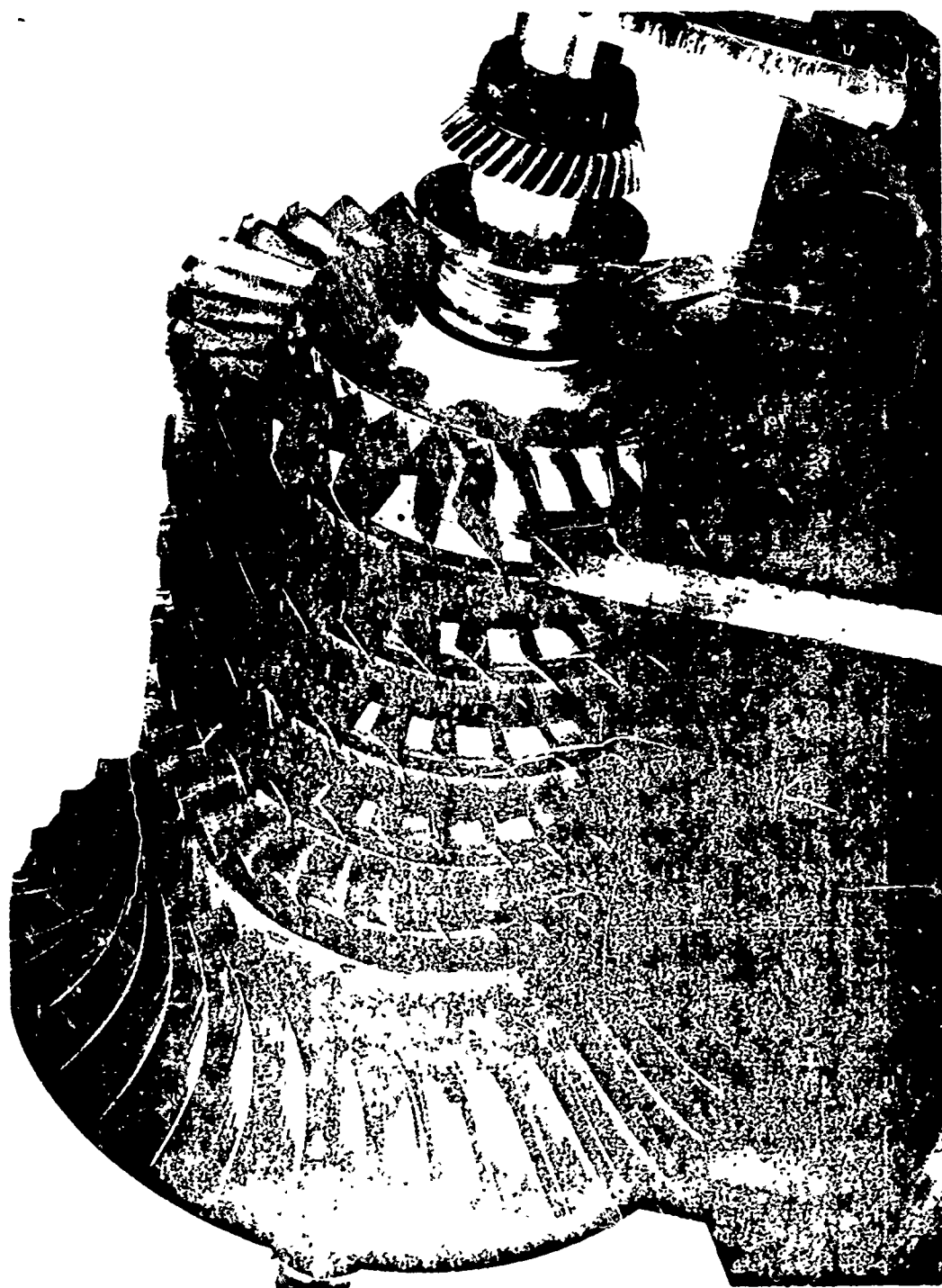


FIGURE 5-6 DISCREPANT COMPRESSOR

TABLE 5.5 UH-1H TRANSMISSION

Page 1 of 2

TRANSMISSION SERIAL NO.	DATE OF RUN	DESCRIPTION OF DISCREPANT	DISCREPANT PAGE NO.	DISCREPANT SERIAL NO.	REMARKS
A12-2655A ABU-11153 ABU-11153 ABU-11153 A12-4216 A12-4216	10/20/70	NO DEFECTS NO DEFECTS NO DEFECTS NO DEFECTS NO DEFECTS NO DEFECTS			RE RUN
A12-258B 812-999 812-6218 A12-759 A12-759	10/22/70	HIGH TIME UNITS HIGH TIME UNITS HIGH TIME UNITS HIGH TIME UNITS HIGH TIME UNITS			RE RUN
ABU-11153 ABU-11153 ABU-11153 ABU-11153 A12-2655A	10/26/70	HAFT BEARING HAFT BEARING HAFT BEARING HAFT BEARING HAFT BEARING	204-040-136-7 204-040-136-7 204-040-136-7 204-040-136-7 204-040-136-7	408R 467C 894C 278K 408R	RUST PITTED BALLS, INNER & OUTER RACES BEARING RUST PITTED BALLS, INNER & OUTER RACES RUST PITTED BALLS, OUTER RACE RUST PITTED BALLS, INNER & OUTER RACES RUST PITTED BALLS, INNER & OUTER RACE
ABU-11153 ABU-11153 A12-4216 A12-2655A	10/28/70	HAFT BEARING HAFT BEARING INPUT QUILL BEARING (TRYPLEX) INPUT QUILL BEARING (TRYPLEX)	204-040-136-7 204-040-136-7 204-040-146-3 204-040-146-3	856E 457 9689-1,2 & 3 3208-1,2 & 3	RUST PITTED BALLS & OUTER RACE RUST PITTED BALLS & OUTER RACE RUST PITTED BALLS & OUTER RACES PITTED OUTER & INNER RACES
A12-4216 A12-2655A ABU-11153 ABU-11864	10/30/70	INPUT QUILL BEARING (TRYPLEX) INPUT QUILL BEARING (TRYPLEX) INPUT QUILL BEARING (TRYPLEX) INPUT QUILL BEARING (TRYPLEX)	204-040-146-3 204-040-146-3 204-040-146-3 205-040-146-3	12350-1,2 & 3 1-510-1,2 & 3 1846-1 & 2 460-1,2 & 3	RUST PITTED BALLS & INNER RACES RUST ON BALLS & OUTER RACES GROOVED INNER RACE & RUSTY BALLS GROOVED INNER RACE & RUSTY BALLS
A12-2655A ABU-11153 A12-4216 ABU-11864	11/3/70	INPUT QUILL BEARING (TRYPLEX) INPUT QUILL BEARING (TRYPLEX) INPUT QUILL BEARING (TRYPLEX) TAIL ROTOR OUTPUT QUILL BEARING (BALL)	204-040-146-3 204-040-146-3 204-040-146-3 204-040-143-1	13728-3 6753-1,2 & 3 J411-1,2 & 3 7510R-1 & 2	PITTED OUTER & INNER RACE PITTED BALLS & INNER & OUTER RACES RUST PITTED BALLS & OUTER RACES CORROSIVE PITTED & SOURCED BALLS
A12-2655A A12-4216 ABU-11864 ABU-11153	11/5/70	TAIL ROTOR OUTPUT QUILL BEARING (BALL) TAIL ROTOR OUTPUT QUILL BEARING (BALL) TAIL ROTOR OUTPUT QUILL BEARING (BALL) TAIL ROTOR OUTPUT QUILL BEARING (BALL)	204-040-143-1 204-040-143-1 204-040-143-1 204-040-143-1	6234R-1 & 2 97976-1 & 2 25040-1 & 2 7145E-1 & 2	PITTED BALLS & OUTER RACES CORROSIVE PITTED BALLS & OUTER RACES PITTED & SOURCED BALLS & OUTER RACES PITTED BALLS

TABLE 5.5 UH-1H TRANSMISSION (continued)

Page 2 of 2

TRANSMISSION SERIAL NO.	DATE OF RUN	DESCRIPTION OF DISCREPANT	DISCREPANT PART NO.	DISCREPANT SERIAL NO.	REMARKS
A12-4214 ABU-11153 ABU-11846	11/9/70	INPUT QUILL BEARING (TRIPLER) TAIL ROTOR OUTPUT QUILL BEARING (BALL) TAIL ROTOR OUTPUT QUILL BEARING (BALL) TAIL ROTOR OUTPUT QUILL BEARING (BALL)	204-040-348-3 204-040-143-1 204-040-143-1 204-040-143-1	A1562-3 7159E-1 & 2 470E-1 & 2 72311-1 & 2	FITTED OUTER & INNER RACES, CUT BALLS RUST FITTED BALLS, INNER & OUTER RACES CORROSIVE FITTING ON ALL BALLS, INNER & OUTER RACES, RUST FITS ON RACES CORROSIVE & RUST FITTING ON ALL BALLS, INNER & OUTER RACES
A12-2655		TAIL ROTOR OUTPUT QUILL BEARING (BALL)	204-040-143-1	72311-1 & 2	
A12-4214 ABU-11153 A12-2655A ABU-11846	11/12/70	TAIL ROTOR OUTPUT QUILL BEARING (BALL) TAIL ROTOR OUTPUT QUILL BEARING (BALL) TAIL ROTOR OUTPUT QUILL BEARING (BALL) TAIL ROTOR OUTPUT QUILL BEARING (ROLLER)	204-040-143-1 204-040-143-1 204-040-143-1 204-040-310-1	69509 38124 44282 101485	CORROSIVE FITTED BALLS & INNER & OUTER RACES RUST FITTED BALLS & OUTER RACES RUST FITTED BALLS & OUTER RACES RUST FITTED INNER RACE
A12-4214 ABU-11153 A12-2655A A12-11846	11/18/70	UPPER SUN GEAR UPPER SUN GEAR UPPER SUN GEAR TAIL ROTOR OUTPUT BEARING (ROLLER)	204-040-330-3 204-040-330-3 204-040-330-3 204-040-310-1	A12-9059 A12-6917 B12-4836 15947-7	LIGHT METAL INDENTS ON ALL TEETH EXCESSIVE WEAR ACROSS TIP OF TEETH METAL BREAKOUT ON SOME TEETH - HEAVY WEAR FITTED INNER RACE GROOVED, FITTED ROLLERS
A12-4214 A12-4214 ABU-11153 A12-2655A ABU-11846	11/20/70	UPPER & LOWER PLANETARY GEARS (PINIONS) UPPER & LOWER PLANETARY GEARS UPPER & LOWER PLANETARY GEARS UPPER & LOWER PLANETARY GEARS UPPER & LOWER PLANETARY GEARS UPPER & LOWER PLANETARY GEARS	UPPER LOWER UPPER LOWER UPPER LOWER UPPER LOWER UPPER LOWER	B12-14247 A12-3406 B12-14247 A12-3406 B12-26C3 A12-113 B12-4022 B12-14028 B12-323 B12-11107	EXCESSIVE WEAR NEAR BASE OF TEETH EXCESSIVE WEAR NEAR BASE OF TEETH (REPIN) METAL INDENTATION SPALLING EDGE OF GEAR TEETH RECESSIVE WEAR ON GEAR TEETH
A12-4214 ABU-11153 A12-2644A ABU-11846	11/24/70	ACCESSORY DRIVE GEARS (PINION) ACCESSORY DRIVE GEARS (PINION) ACCESSORY DRIVE GEARS (PINION) ACCESSORY DRIVE GEARS (PINION)	204-040-762-1 204-040-762-1 204-040-762-1 204-040-762-1	F12-145 B12-1807 B12-1450 B12-687 A12-592	RUST FITTING ON SOME TEETH EXCESSIVE WEAR - SPALLING IN GEAR TEETH HEAVY WEAR ON ONE END OF TEETH EXCESSIVE WEAR SPALLING IN GEAR TEETH
B12-999 B12-621 A12-2588 A12-7598	12/1/70	HIGH TIME UNIT AFTER OVERHAUL HIGH TIME UNIT AFTER OVERHAUL HIGH TIME UNIT AFTER OVERHAUL HIGH TIME UNIT AFTER OVERHAUL			NO DEFECTS NO DEFECTS NO DEFECTS NO DEFECTS
A12-4214 ABU-11846 ABU-11153 A12-2655A	12/2/70	NO DEFECTS NO DEFECTS NO DEFECTS NO DEFECTS			

TABLE 5.6 UH-1H 42° AND 90° GEARBOXES - TEST CELL

90° GEAR BOX SERIAL NO.	42° GEAR BOX SERIAL NO.	DATE OF RUN	DESCRIPTION OF DISCREPANCY	DISCREPANCY PART NO.	DISCREPANCY SERIAL NO.	REMARKS
ABC-142	B12-2925	10/21/70	NO DEFECTS			
A13-2772	B13-5199	10/21/70	NO DEFECTS			
A13-2065	AB8-289	10/21/70	NO DEFECTS			
A13-6624	B13-8304	10/21/70	NO DEFECTS			
B13-10061	B13-4023	10/23/70	HIGH TIME UNIT			
B13-8329	B13-2950	10/23/70	HIGH TIME UNIT			
B13-8420	B13-5572	10/23/70	HIGH TIME UNIT			
B13-9443	A13-854	10/23/70	HIGH TIME UNIT			
B13-6624	B13-8304	10/27/70	INPUT QUILL BEARING	204-040-406-1	2011	FATIGUE FITTED OUTER RACE & R
ABC-142	B13-2525	10/27/70	INPUT QUILL BEARING	204-040-310-1	101799	RUSTY FITTED ROLLERS
A13-2065	AB8-289	10/27/70	INPUT QUILL BEARING	204-040-406-1	30053	FATIGUE FITTED OUTER RACE & R
A13-2772	B13-5199	10/27/70	INPUT QUILL BEARING	204-040-310-1	153203	FITTED INNER RACE AND GROOVES
A13-2772	B13-5199	10/27/70	INPUT QUILL BEARING	204-040-406-1	4238	FATIGUE FITTED OUTER RACE
A13-2772	B13-5199	10/27/70	INPUT QUILL BEARING	204-040-310-1	13356	FITTED INNER RACE & ROLLERS
A13-2772	B13-5199	10/27/70	INPUT QUILL BEARING	204-040-406-1	10063	FATIGUE FITTED OUTER RACE
A13-2772	B13-5199	10/27/70	INPUT QUILL BEARING	204-040-310-1	103524	CORROSIVE FITTED ROLLER -- F
ABC-142	B13-2925	10/29/70	OUTPUT QUILL BEARING	204-040-406-1	13799	FATIGUE FITTED OUTER RACE
A13-2065	AB8-289	10/29/70	INPUT QUILL BEARING	204-040-143-1	15740-2 & 3	FITTED BALLS & OUTER RACE
A13-2065	AB8-289	10/29/70	INPUT QUILL BEARING	204-040-406-1	13322	FITTED OUTER RACE
A13-2065	AB8-289	10/29/70	INPUT QUILL BEARING	204-040-310-1	5354	FITTED INNER RACE, GROOVES
A13-2065	AB8-289	10/29/70	INPUT QUILL BEARING	204-040-143-1	38305	RUSTY, FITTED BALLS & OUTER
A13-2065	AB8-289	10/29/70	INPUT QUILL BEARING	204-040-310-1	13378	FITTED INNER RACE GROOVES
A13-2065	AB8-289	10/29/70	INPUT QUILL BEARING	204-040-143-1	25821	RUSTY, FITTED BALLS, FITTED
A13-2065	AB8-289	10/29/70	INPUT QUILL BEARING	204-040-143-1	905K-1 & 2	CORROSIVE FITTED BALLS & R

TABLE 5.6 UH-1H 42° AND 90° GEARBOXES - TEST CELL (Continued)

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90° GEAR BOX SERIAL NO.	42° GEAR BOX SERIAL NO.	DATE OF RUN	DESCRIPTION OF DISCREPANT	DISCREPANT PAGE NO.	DISCREPANT SERIAL NO.	REMARKS
ABC-142	B13-2925	11/2/70	INPUT QUILL BEARING	204-040-143-1	86470-2	FITTED OUTER RACE - FLANKING OUTER RACE
			OUTPUT QUILL BEARING	204-040-143-1	56840-1 & 2	FITTED BALLS & OUTER RACES
A13-2065	ABB-289	11/2/70	INPUT QUILL BEARING	204-040-143-1	38124	RUSTY, FITTED BALLS & OUTER RACES
			OUTPUT QUILL BEARING	204-040-143-1	50350-1 & 2	FITTED & CUT BALLS
B13-6624		11/2/70	INPUT QUILL BEARING	204-040-143-1	91720-1 & 2	RUSTY BALLS & OUTER RACES
			OUTPUT QUILL BEARING	204-040-143-1	44221-1 & 2	FITTED & CUT BALLS
A13-2772	B13-8304	11/2/70	INPUT QUILL BEARING	204-040-143-1	80178-1 & 2	SCORED & PITTED BALLS
			OUTPUT QUILL BEARING	204-040-143-1	69599	CORROSIVE, FITTED BALLS AND OUTER & INNER RACES
B13-2065	B13-5199	11/4/70	OUTPUT QUILL BEARINGS	204-040-407-3	22283	CORROSIVE FITTED OUTER RACES & ROLLERS
			INPUT & OUTPUT GEARS	204-040-500-9	6276	SLIGHT SCUFF ON GEAR TEETH
				204-040-500-10	A13-3000	FITTING ON GEAR CENTER PART OF PATTERN
B13-6624		11/4/70	OUTPUT QUILL BEARING	204-040-407-3	7682	FITTED OUTER RACE & FITTED, RUSTY ROLLERS
	B13-8304		INPUT & OUTPUT GEARS	204-040-500-9	13896	PATTERN TOO HIGH, SCUFFED AT END OF TEETH
				204-040-500-10	11983	PATTERN LOW AND SLIGHTLY SCUFFED
A13-2772		11/4/70	OUTPUT QUILL BEARING	204-040-407-3	19729	RUSTY, FITTED OUTER RACE & ROLLERS
	B13-2925		INPUT & OUTPUT GEARS	204-040-500-9	A13-11597	PATTERN HEAVY & SLIGHTLY SCUFFED
				204-040-500-10	A13-2052	LOW PATTERN AND SLIGHTLY SCUFFED
ABC-142	ABB-289	11/4/70	OUTPUT BEARING	204-040-407-3	26767	FATIGUE FITTED OUTER RACE & ROLLERS
			INPUT & OUTPUT GEARS	204-040-500-9	24867	PATTERN TOO HIGH
				204-040-500-10	B13-5905	GEAR TEETH HAVE A WORN & SCUFFED AREA
A13-2772	B13-2925	11/6/70	OUTPUT BEARING	204-040-407-3	15392	FITTED OUTER RACE & RUSTY FITTED ROLLERS
			INPUT & OUTPUT GEARS	204-040-500-9	B12-8720	PATTERN RUNNING OFF TOP OF GEAR TEETH
				204-040-500-10	15427	PATTERN LOW AND SLIGHTLY SCUFFED & FITTED
B13-6624		11/6/70	OUTPUT QUILL BEARING	204-040-407-3	7682	FITTED OUTER RACE & RUSTY FITTED ROLLERS
	B13-8304		OUTPUT QUILL BEARING	204-040-407-3	80681-1 & 2	CORROSIVE FITTED BALLS, INNER & OUTER RACES
			OUTPUT QUILL BEARING	204-040-407-3	22032	RUST FITTED OUTER RACE & ROLLERS
ABC-142	ABB-289	11/6/70	OUTPUT QUILL BEARING	204-040-407-3	A13-747	PATTERN TORN IN - TOO LOW
			INPUT & OUTPUT GEARS	204-040-500-9	14441	PATTERN TOO LOW
				204-040-500-10	21312	ROUGH, FITTED BALLS & OUTER RACE
A13-2065	B13-5199	11/6/70	OUTPUT QUILL BEARING	204-040-424-2	101619	FITTED INNER RACE & GROOVED ROLLERS

TABLE 5.6 UH-1H 42° AND 90° GEARBOXES - TEST CELL (Continued)

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90° GEAR BOX	42° GEAR BOX	DATE	DESCRIPTION OF DISCREPANT	DISCREPANT PART NO.	DISCREPANT SERIAL NO.	REMARKS
ABC-142	AB3-289	11/10/70	OUTPUT QUILL BEARING	204-040-424-1	J-369	ROUGH-FATIGUE FLAKING OUTER RACE & BALLS
			INPUT QUILL BEARING	204-040-143-1	97976-1 & 2	CORROSIVE PITTED BALLS & OUTER RACES
A13-2065	B13-5199	11/10/70	OUTPUT QUILL BEARING	204-040-424-1	10986	ROUGH PITTED OUTER RACE & BALLS
			OUTPUT QUILL BEARING	204-040-143-1	38948-1 & 2	CORROSIVE PITTING ON ALL BALLS, INNER & OUTER RACES, RUST FITS ON INNER & OUTER RACES ARE INTERMITTENTLY ALL AROUND RACES
B13-6624	B13-8304	11/10/70	OUTPUT QUILL BEARING	204-040-424-1	6851	ROUGH PITTED OUTER RACE & BALLS
			OUTPUT QUILL BEARING	204-040-143-1	37966-1 & 2	CORROSIVE & RUST PITTING ON ALL BALLS & INNER & OUTER RACES
A13-2772	B13-2925	11/10/70	OUTPUT QUILL BEARING	204-040-143-1	6378	ROUGH, PITTED OUTER RACE & BALL
			INPUT QUILL BEARING	204-040-143-1	A8820	CORROSION & RUST ON ALL BALLS, INNER & OUTER RACES
A13-2065		11/13/70	INPUT & OUTPUT GEARS	204-040-410-7	B13-10265	SCUFFED GEAR TEETH
	B13-5199		NO DEFECTS	204-040-400-9	B13-12897	SCUFFED ON BACK OF GEAR TEETH
A13-2772		11/13/70	INPUT & OUTPUT GEARS	204-040-401-7	E-803	SCUFFED GEAR TEETH
	B13-2925		OUTPUT QUILL BEARING	204-040-143-1	A13-1637	SCUFFED BACK OF GEAR
			INPUT & OUTPUT GEARS	204-040-401-7	7159E	RUST PLCS ON INNER & OUTER RACES INTERMITTENTLY
B13-6624	B13-8304	11/13/70	INPUT & OUTPUT GEARS	204-040-401-7	A13-2619	SLIGHT SCUFFED & SCUFF ON BACK
			NO DEFECTS	204-040-400-9	B13-12073	90° BEVEL GEAR TEETH SCUFFED
ABC-1-2	AB3-289	11/13/70	INPUT & OUTPUT GEARS	204-040-401-7	B13-13033	PITTED GEAR TEETH
			OUTPUT QUILL BEARINGS	204-040-143-1	72311	SCUFFED GEAR TEETH
A13-2065	B13-4062	11/17/70	INPUT & OUTPUT GEARS	204-040-401-7	9737	CORROSIVE PITTING ON ALL BALLS, INNER & OUTER RACES
			SLAVE UNIT	204-040-400-9	4014	PITTING & SCUFFING ON BACK SIDE SCUFFING
A13-2772	B13-4062	11/17/70	INPUT & OUTPUT GEARS	204-040-401-7	B12-3802	SPALLING AT CUNTER OF TEETH
			SLAVE UNIT	204-040-400-9	3447	SCUFFING
ABC-142	B13-4062	11/17/70	INPUT & OUTPUT GEARS	204-040-401-7	SLP-741	EXCESSIVE SCUFFING
			SLAVE UNIT	204-040-401-7	11196	SCUFFING BACK SIDE OF TEETH
B13-6624	B13-4062	11/17/70	INPUT & OUTPUT GEARS	204-040-401-7	4007	SCUFFING BACK SIDE OF TEETH
			SLAVE UNIT	204-040-400-9	A13-1199	SCUFFING

TABLE 5.6 UR-1H 42° AND 90° GEARBOXES - TEST CELL (Continued)

Page 4 of 4

90° GEAR BOX SERIAL NO.	42° GEAR BOX SERIAL NO.	DATE OF TEST	DESCRIPTION OF DISCREPANT	DISCREPANT PART NO.	DISCREPANT SERIAL NO.	REMARKS
B13-6624		11/19/70	INPUT & OUTPUT GEARS	204-040-400-9	A13-2040	SCUFFED TEETH
	B13-4062		NO DEFECTS - PMOD. SLAVE	204-040-401-7	A13-2084	FITTING
A13-2065		11/19/70	INPUT & OUTPUT GEARS	204-040-401-5	B13-14128	LIGHT MUST FITTING ON SOME TEETH
	A13-4062		NO DEFECTS - PMOD. SLAVE	204-040-400-9	5833	FITTING
A13-2772		11/19/70	INPUT & OUTPUT GEARS	204-040-401-5	B13-2009	LIGHT SPALLING AT CENTER OF A PEA TEETH
	B13-4062		REP. - SLAVE UNIT	204-040-400-9	10524	FITTED & SCUFFED TEETH
ABC-142		11/19/70	INPUT & OUTPUT GEARS	204-040-401-7	A13-1259	HEAVY WEAR & SPALLING
	A13-4062		NO DEFECTS - SLAVE UNIT	204-040-400-9	11664	FITTING
A13-2772		11/23/70	NO DEFECTS			ALL ORIGINAL PARTS REINSTALLED. DUE TO THE AMOUNT OF ASSEMBLY & DISASSEMBLY & TEST RUNNING, THIS IS NOT THE SAME AS A REBUILT & QUALIFIED BOX.
	B13-2925		NO DEFECTS			
ABC-142		11/23/70	NO DEFECTS			
	ABB-289		NO DEFECTS			
A13-2065		11/23/70	NO DEFECTS			
	B13-5199		NO DEFECTS			
B13-6624		11/23/70	NO DEFECTS			
	B13-8304		NO DEFECTS			
B13-8420		11/24/70	HIGH TIME - AFTER OVERHAUL			
	A13-854		HIGH TIME - AFTER OVERHAUL			
B13-10061		11/24/70	HIGH TIME - AFTER OVERHAUL			
	B13-4023		HIGH TIME - AFTER OVERHAUL			
B13-4329		11/24/70	HIGH TIME - AFTER OVERHAUL			
	B13-2950		HIGH TIME - AFTER OVERHAUL			
B13-9443		11/24/70	HIGH TIME - AFTER OVERHAUL			
	B13-5272		HIGH TIME - AFTER OVERHAUL			

In the gearbox testing the defective parts used were as follows:

- a) Input bearings (21)
- b) Output bearings (19)
- c) Input gears (18)
- d) Output gears (18)

## 5.7 DATA EVALUATION

### 5.7.1 DATA REDUCTION

As previously discussed, data from the test cells was recovered in several forms. These were magnetic tape data, MRS data, oscillograph data, and manual recordings. All data were analyzed at NED in Palos Verdes, California. Following each day's testing a data package was shipped by air carrier to Palos Verdes. Before data transmittal, however, magnetic tape data was screened at ARADMAC for valid information content. In addition, MRS CIPR data was transferred by the MRS Data Recovery Unit (DRU) to a coded strip paper display.

After receipt of the data package, the magnetic tape data, which consisted of vibration signals, was machine reduced to power spectral density plots. Engine performance parameters contained in the oscillograph data were manually reduced and normalized. DRU printout data were inserted into a computer program which converted the coded engine parameter values to physical units and performed normalization and operational functions on the parameters.

### 5.7.2 VIBRATION

#### 5.7.2.1 Data Analysis Procedures

- a) Wideband Root Mean Square (RMS) Threshold Detection

This technique was investigated to possibly provide an easy indication of good or bad condition for the machines under test. It was hoped that with the onset of failure, the overall (RMS) vibration level would rise sufficiently above its normal level so that a simple threshold circuit

could determine good from bad. Unfortunately, this scheme did not facilitate the test bed goal of fault detection. The vibration level was a function of power setting, accelerometer location, and machine serial number. Changes occurring in the vibration signals due to the implanting of discrepant parts were uncorrelated by the wideband RMS threshold detection techniques.

b) **Narrowband RMS Threshold Detection**

It was felt from the outset that certain narrow bands of frequencies might be sensitive to component degradation. Various bands were examined with mixed results. By obtaining basic signature data for a given serial number machine, and observing deviations from normal, a satisfactory degree of success was obtained.

The band pass filters were placed at various frequencies; the most predominant used were 100 and 180 Hz. The main drawback to this scheme was that the thresholds varied as a function of both serial number and power level of the machine. This method was not considered sufficiently reliable for continued implementation.

c) **Spectral Vector and Ratio Method**

The Spectral Vector and the Ratio Method which do not have the limitations of the previously mentioned schemes were fully developed. The results of these analysis techniques follow.

5.7.2.2 **Results of Vibration Analysis Techniques**

The machines studied in the MRS program were analyzed as if they were black boxes. No attempt was made to correlate the noise emission from the machine with its internal components. This should not be construed to mean that a correlation cannot be made between the noise emission and the faulty part causing that emission, but it means that there is no way of (precisely) predicting ahead of time what that noise spectra will be for various faulty

components--especially the secondary effects of these components. These "black box" machines were analyzed totally by their emitted spectra as obtained by experimentation. The engine was characterized by the Spectral Vector Concept, while the gear boxes and transmissions were analyzed by the Ratio Method (the ratio method is a special case of the Spectral Vector - reference Sections 3.3.1 and 7.9)

#### 5.7.2.3 Results of MRS Data Reduction

Figure 5-7 illustrates a typical power spectral density plot for a serviceable 90° gear box. Band number 1 and band number 2, as marked on the figure, are the frequency bands of interest. Notice how the peak in the lower frequency band is considerably higher than the peak in the higher frequency band. The ratio of the peak in the higher frequency band to the peak in the lower frequency band is .015:1. Contrast Figure 5-8 with Figure 5-7. Figure 5-8 illustrates the PSD of a 90-degree gear box with a defective output roller bearing. Notice that the peak in the higher frequency band is ten times greater than the peak in the lower frequency band.

Figure 5-9 is a summary of the 90-degree gear box test cell analysis. Notice the excellent separation of "good" from "bad". The dots are data points for each unit analyzed. The High Time units (gear boxes in for routine overhaul after prescribed service time) have ratios that fall far to the left in the "good" column which seem to indicate that these units have a considerable amount of service left before they should be overhauled.

Figure 5-10 summarizes the 42-degree gear box test cell analysis. The frequency bands used for this analysis were those determined from the flight data, and as a result, the detection of scuffed gears did not occur. This test cell analysis was done in retrospect to see what kind of correlation could be made between flight data and test cell data. It appears that if defective gears are to be detected in the test cell, then the bands should be adjusted similarly to those of the 90-degree gear box.

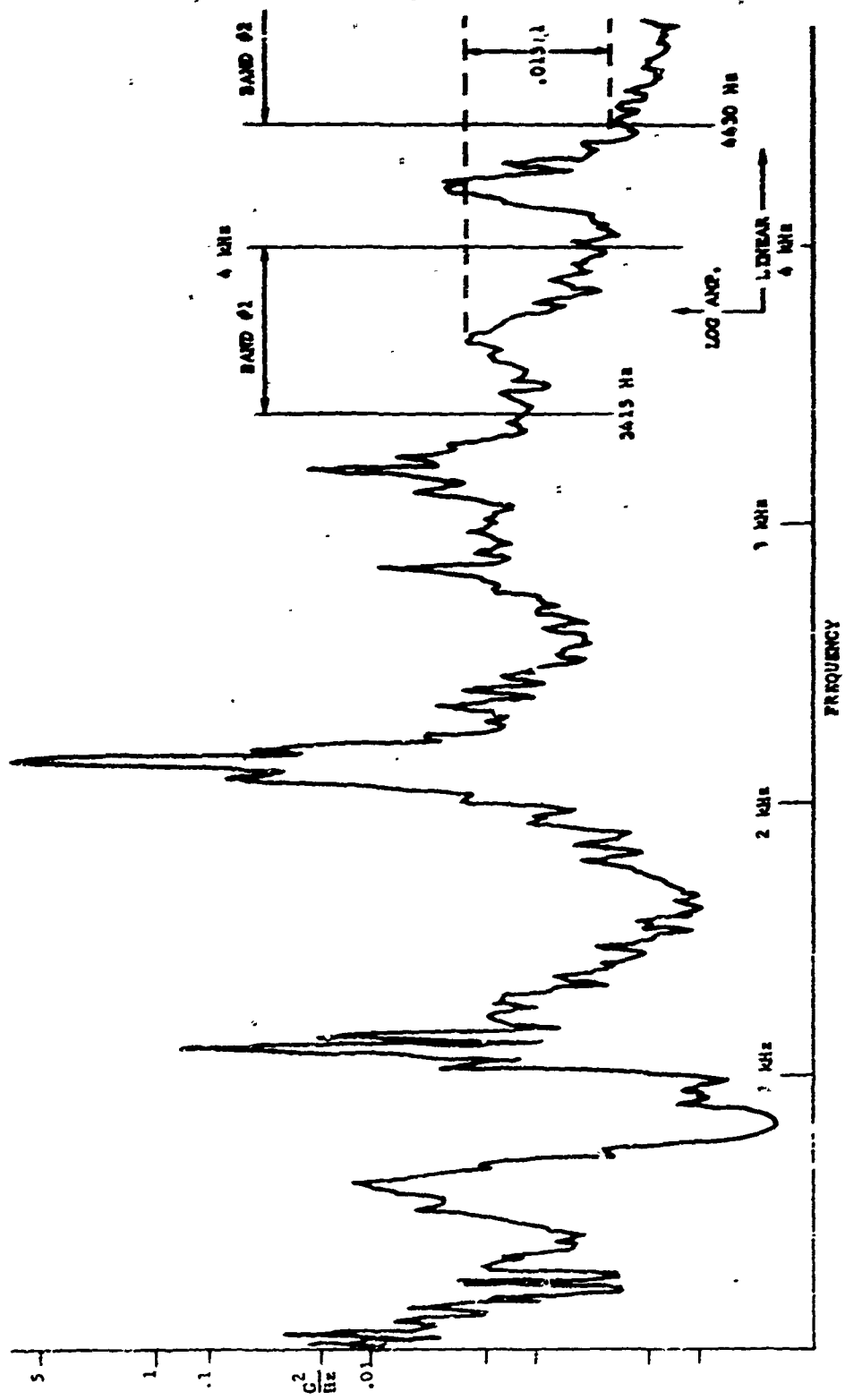


FIGURE 5-7 PSD PLOT OF A GOOD 90° GEARBOX

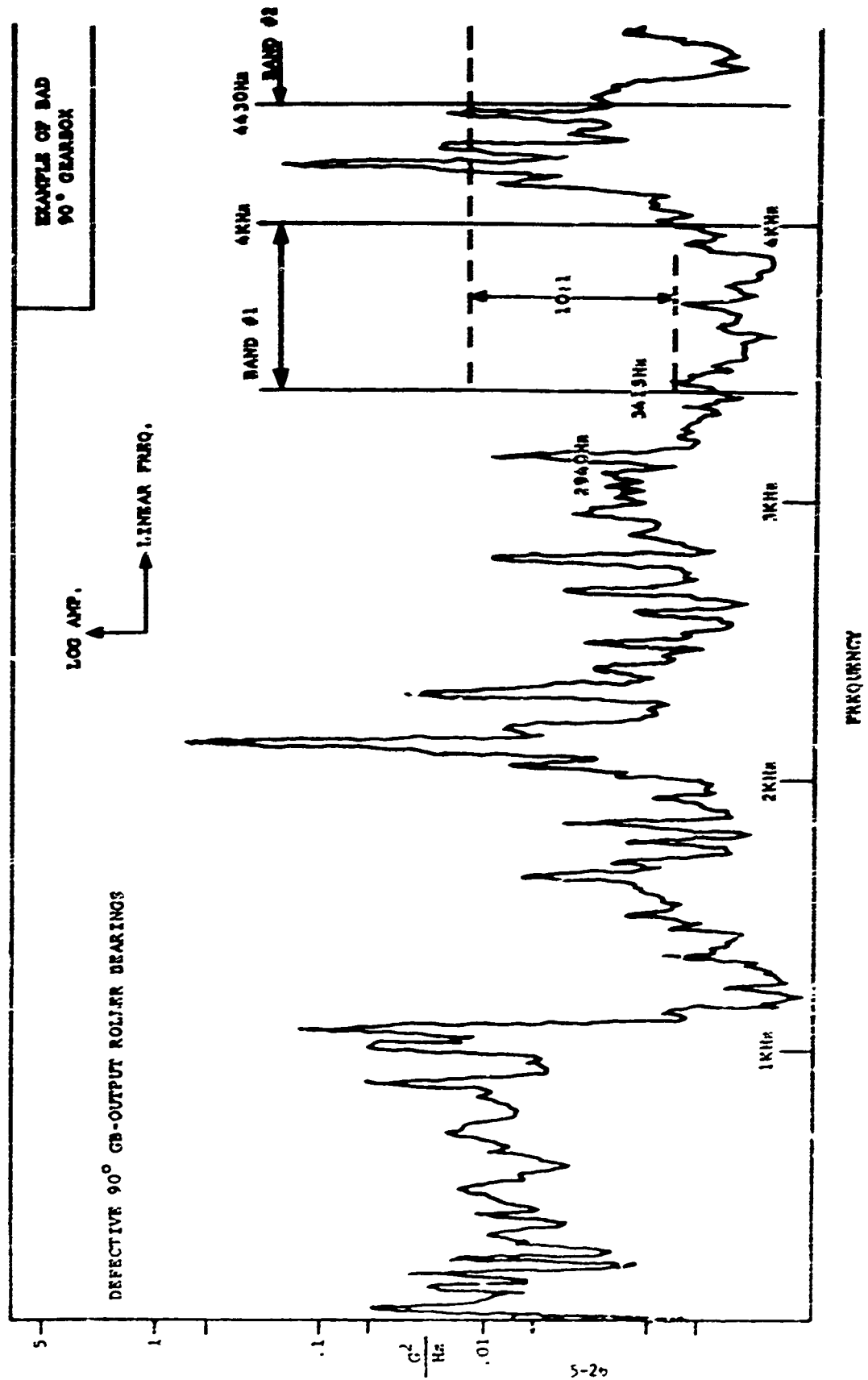


FIGURE 5-8 PSD PLOT OF A BAD 90° GEARBOX

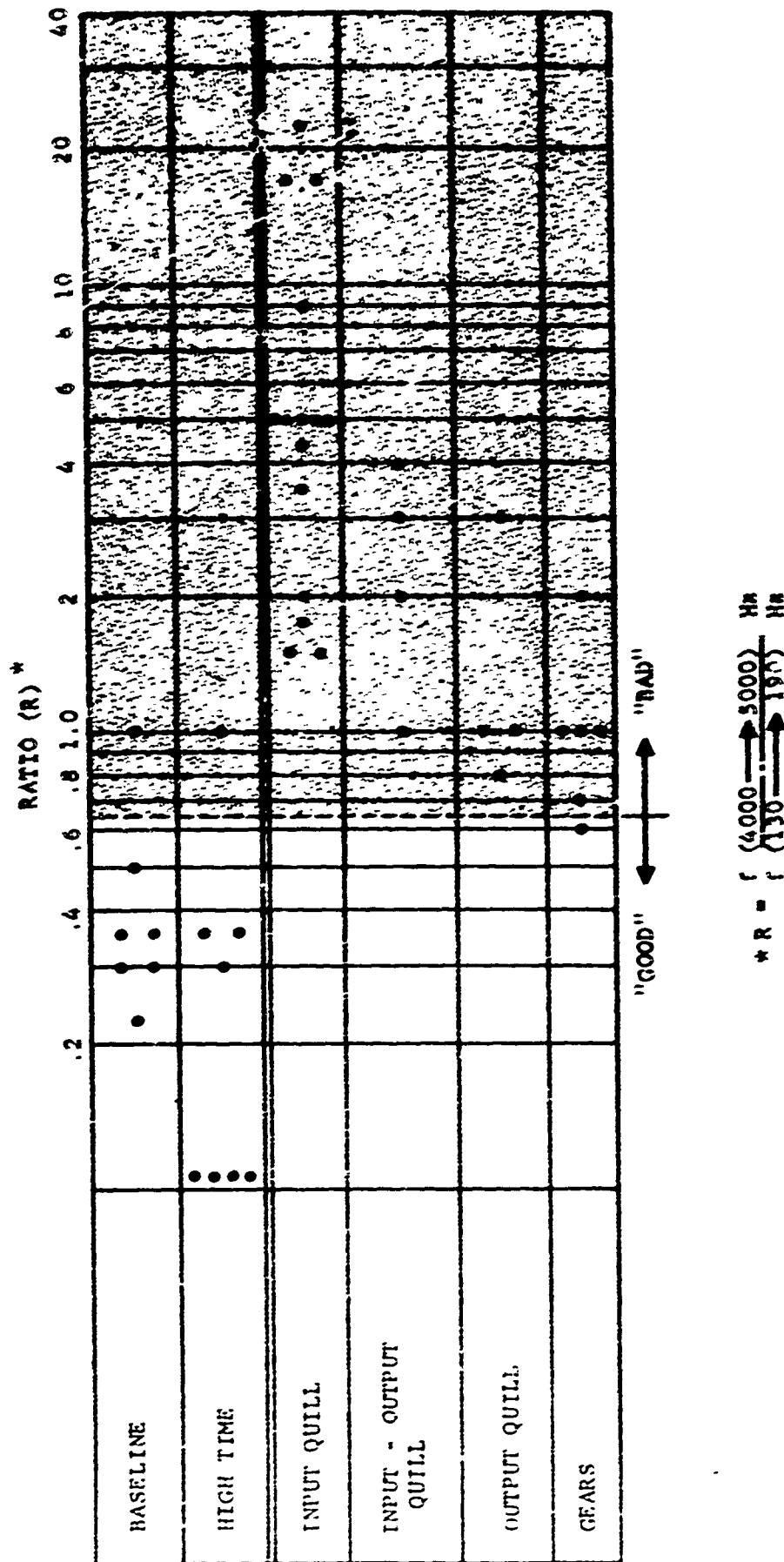


FIGURE 5-9 90° GRABBOX TEST CELL DATA SUMMARY

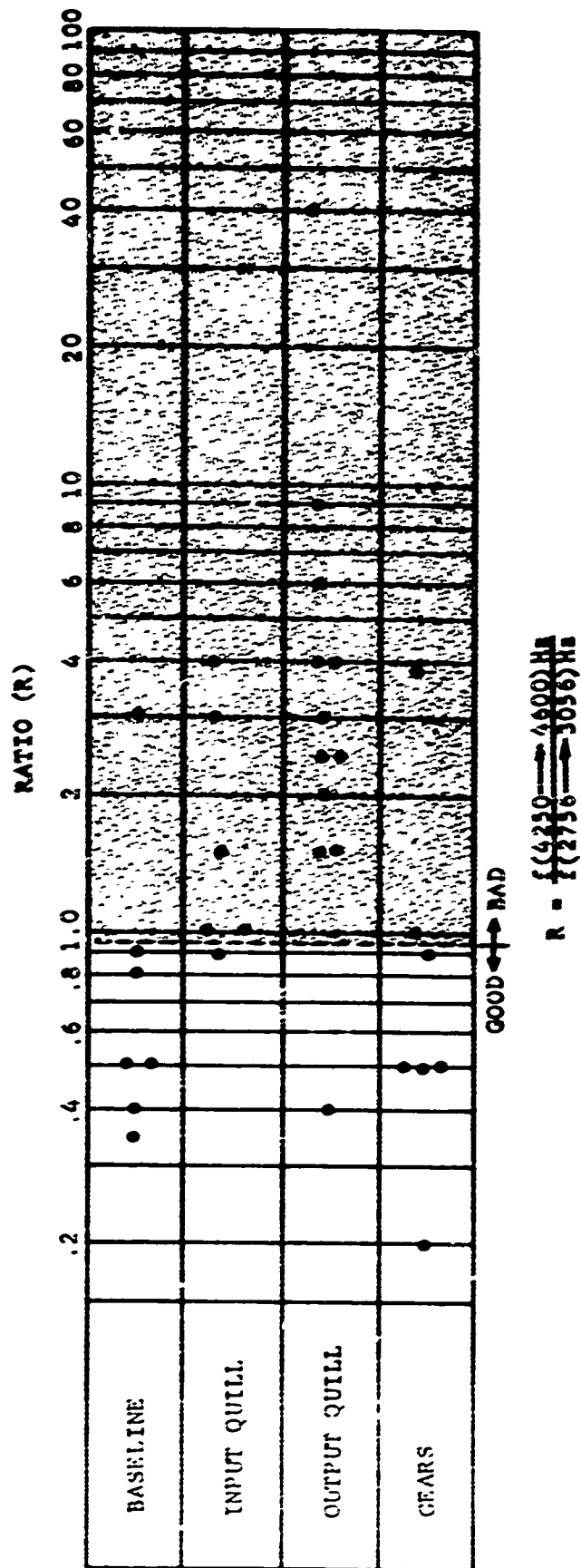


FIGURE 5-10 42° GEARBOX TEST CELL SUMMARY

Figure 5-11 summarizes the results of the transmission test cell data. Despite the fact that the transmission is a considerably more complex component than the 90-degree gear box, the separation of "good" from "bad" by the ratio method is excellent.

As mentioned previously, the engine was characterized by a spectral vector. Figure 5-12 illustrates the normalized five-place spectral vector with the first place normalized to level 2.

Figure 5-13 presents a summary of the test cell data analyzed using the spectral vector, as defined in Figure 5-12. The transducer location used was at the aft end of the compressor section. Perfect separation of good from bad did not occur; however, the results are extremely promising. By shifting the frequency bands, various degrees of separation result.

The four-place error code gives rise to 256 possible combinations of four-digit codes. In reducing the test cell data, only 26 unambiguous codes were found for the engine and 11 of these were codes for good engines. Therefore, of the total of 256 possible codes, 230 were not defined; i.e., 88 percent of the codes were undefined. Because of the complexity of analyzing a four-dimensional problem by hand, no reliable method of determining the undefined codes was found. In view of this fact and the level of complexity needed to implement the four-place spectral vector in hardware, this method was not pursued further than the test cell analysis.

### 5.7.3 ENGINE GAS FLOW ANALYSIS

This section covers the evaluation of the test data on the T53-L-13 engine, conducted during the ARADMAC test cell phase of the MRS program. The preceding Table 5.4 presented the engine and discrepant parts selected for this phase.

#### 5.7.3.1 Baseline Evaluation

The test cell data from the ten T53-L-13 engines have been evaluated to determine if a common baseline engine performance value can be established by using the averaged values. Direct comparison of the corrected engine performance parameters for ambient conditions are presented in figures 5-14 through 5-18 for the following normalized engine performance relationships.

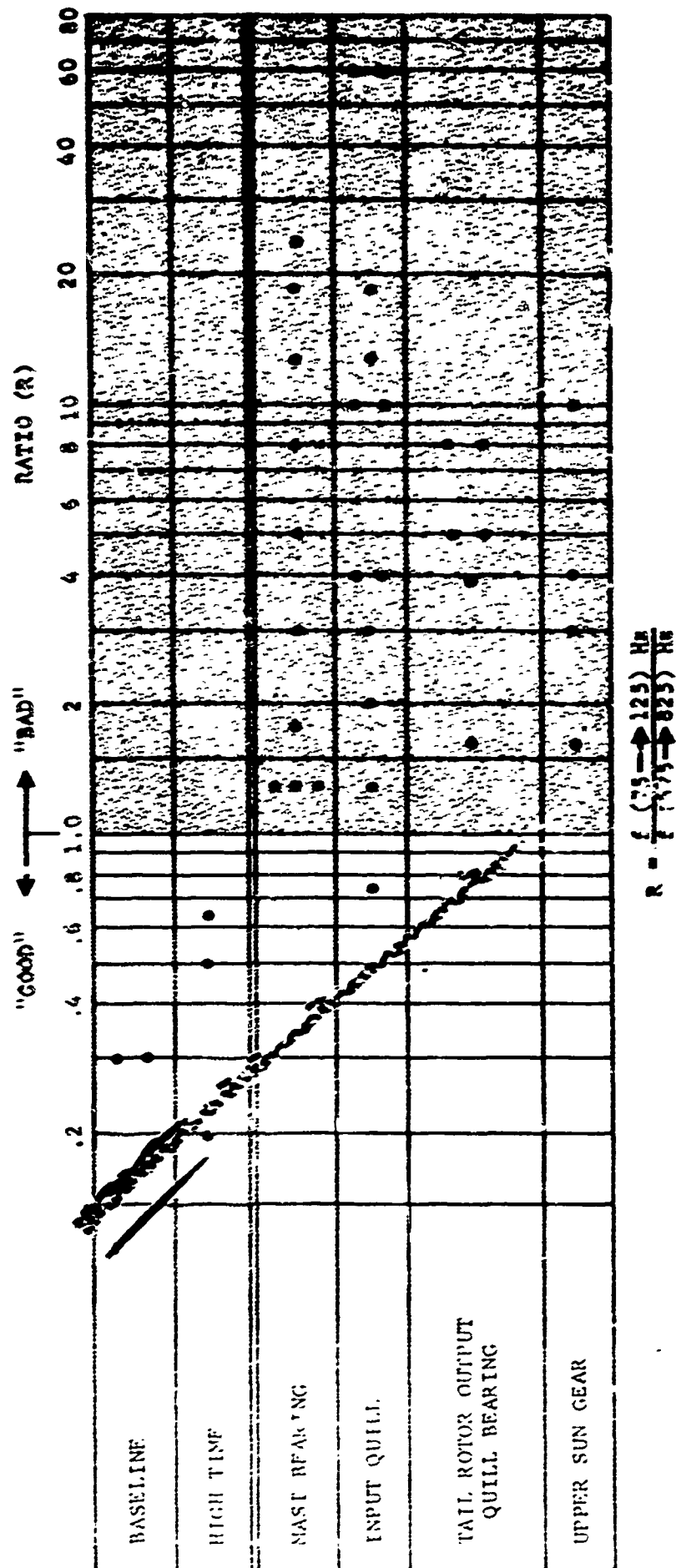
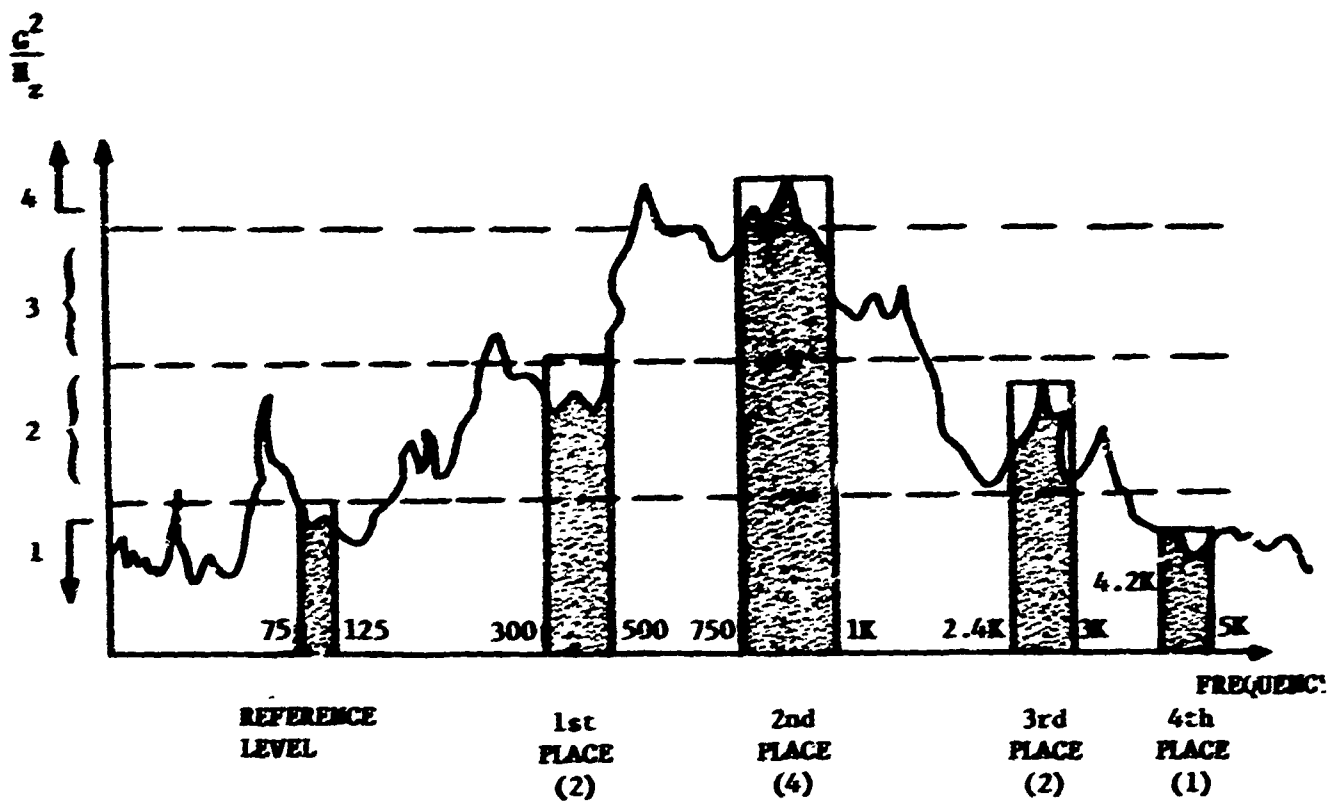


FIGURE 5-11 TRANSMISSION TEST CELL DATA SUMMARY



CODE = 2421

FIGURE 5-12 EXAMPLE OF SPECTRAL VECTOR IN ENGINE TEST CELL

NORMALIZED CODES	BEARINGS			COMPRESSOR	TURBINE	FUEL CONTROL	GOOD ENGINES
	2	3	4				
2232	xxx						
2301						xx	
2312			x				
2333	xx						
3211		x					
3233		xx	xx				
3311			x				
3322	x			xxxx			
3333	x	x	x		x		
4301					x		
4401					x		
4412			x		x		
4422	x						
4432				x			
2221							x
2332							x
3232							xxxxx
3242							x
3332							xxxxxxxxxxxx
3342							xx
3432							x
3442							x
3443							x
4343							x
4442							x

FIGURE 5-13 SUMMARY OF ERROR CODES FOR ENGINE TEST CELL DATA

- Compressor pressure ratio (CPR) versus corrected engine speed ( $N_1/\sqrt{\theta}$ )
- Corrected shaft horsepower (SHP/ $\sqrt{\theta}$ ) versus corrected engine speed ( $N_1/\sqrt{\theta}$ )
- Corrected exhaust gas temperature EGT/ $\sqrt{\theta}$  versus corrected engine speed ( $N_1/\sqrt{\theta}$ )
- Corrected engine fuel flow ( $W_F/\sqrt{\theta}$ ) versus corrected engine speed ( $N_1/\sqrt{\theta}$ )
- Corrected shaft horsepower (SHP/ $\sqrt{\theta}$ ) versus engine fuel flow ( $W_F/\sqrt{\theta}$ )

The selected performance parameter relationships provide adequate information to effectively diagnose the engine component faults. An evaluation of Figures 5-14 through 5-18 which present the composite of eleven nondefective engines, show the significant engine-to-engine performance variations. It clearly indicates that each engine has unique performance characteristics. Due to the gross performance variation and the minor nature of the discrepancies, the specific baseline engine signature data were used to identify the discrepant engine part rather than the average operating lines.

#### 5.7.3.2 Baseline-Discrepant Correlation

The results of the baseline engine and discrepant parts data obtained during the test cell phase are covered in this section. Table 5.4 summarized the T53-L-13 engine tests during the period 12 October 1970 to 24 November 1970. Direct performance comparisons of the baseline and discrepant part embedded engines are presented in figures 5-19 through 5-43 and discussed in the following paragraphs.

The effects of discrepant main shaft bearings (number 4) and misrigged fuel control unit on the engine performance were determined using engine LE15351. Three engine runs had been conducted on an engine with degraded number 4 bearings. Specific baseline engine signature data were obtained before and after the three discrepant number 4 bearing engine runs. The following conclusions were established from a direct comparison of the discrepant number 4 bearing and baseline engine performance presented in figures 5-19 through 5-23.

- 1) As anticipated, the defective main shaft bearings have little effect on the compressor performance. The resultant compressor pressure ratios of the discrepant engines are within the baseline values.

# TEST CELL PHASE-NONDEFECTIVE ENGINES

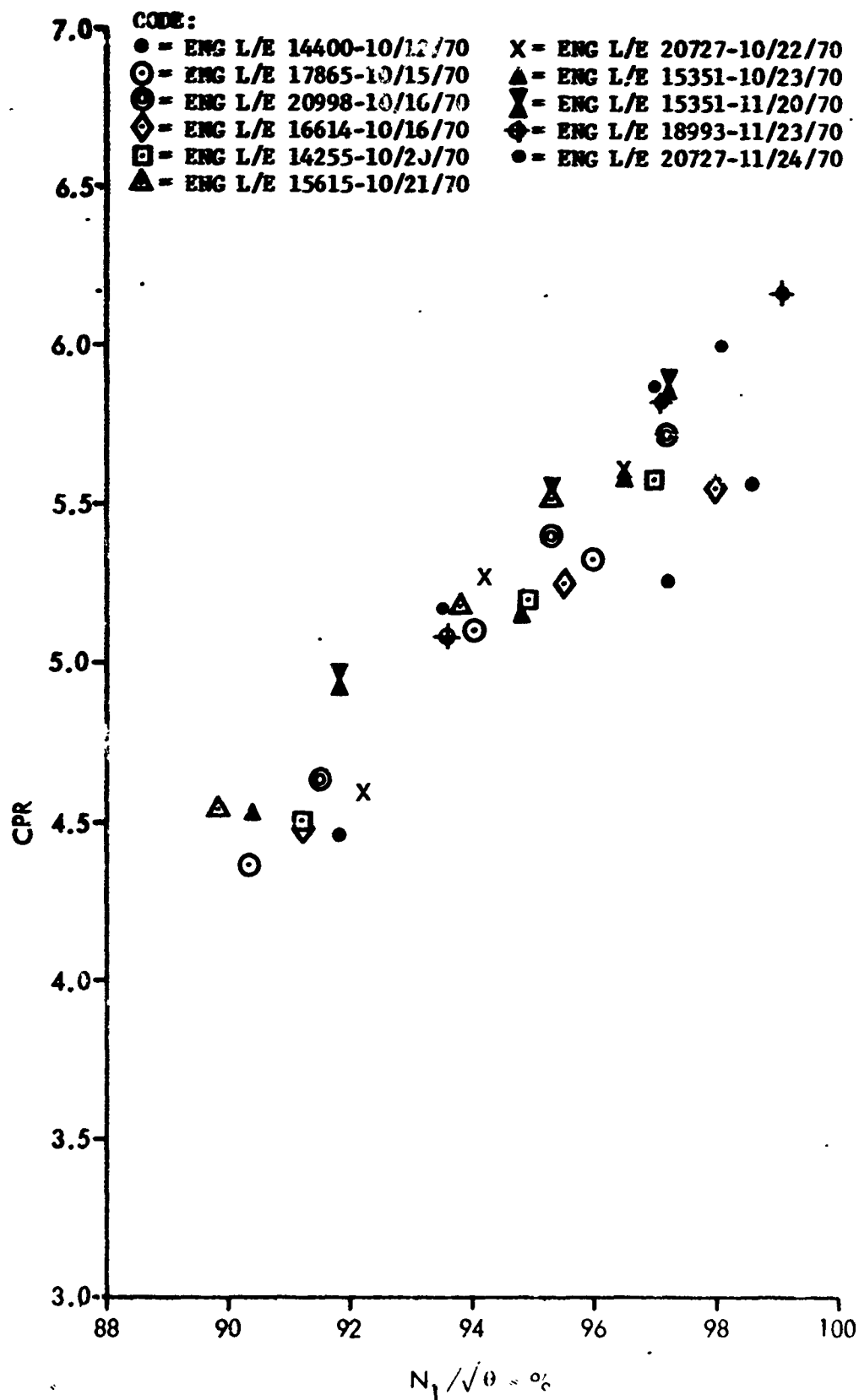


FIGURE 5-14 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

# TEST CELL PHASE-NONDEFECTIVE ENGINES

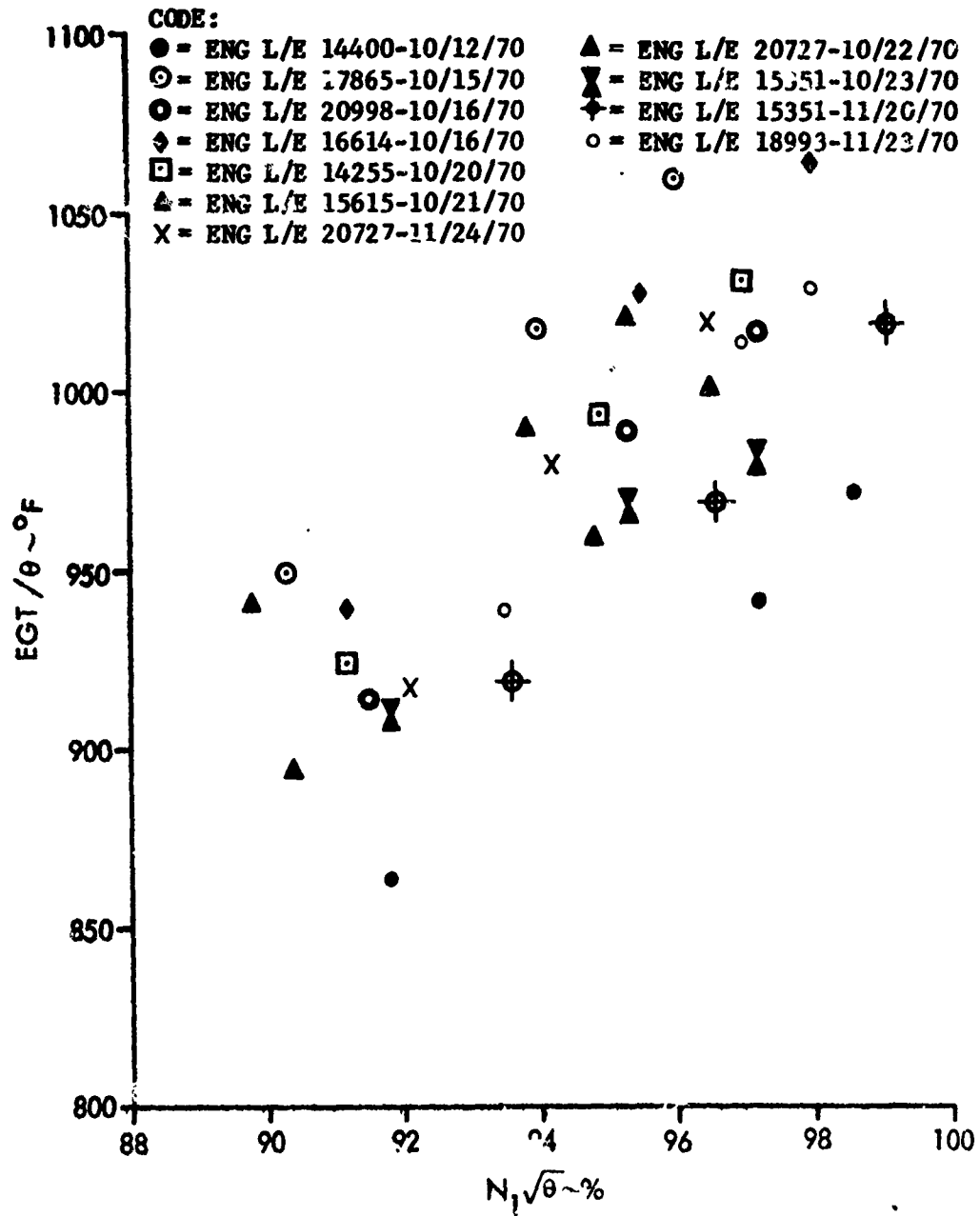


FIGURE 5-15 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

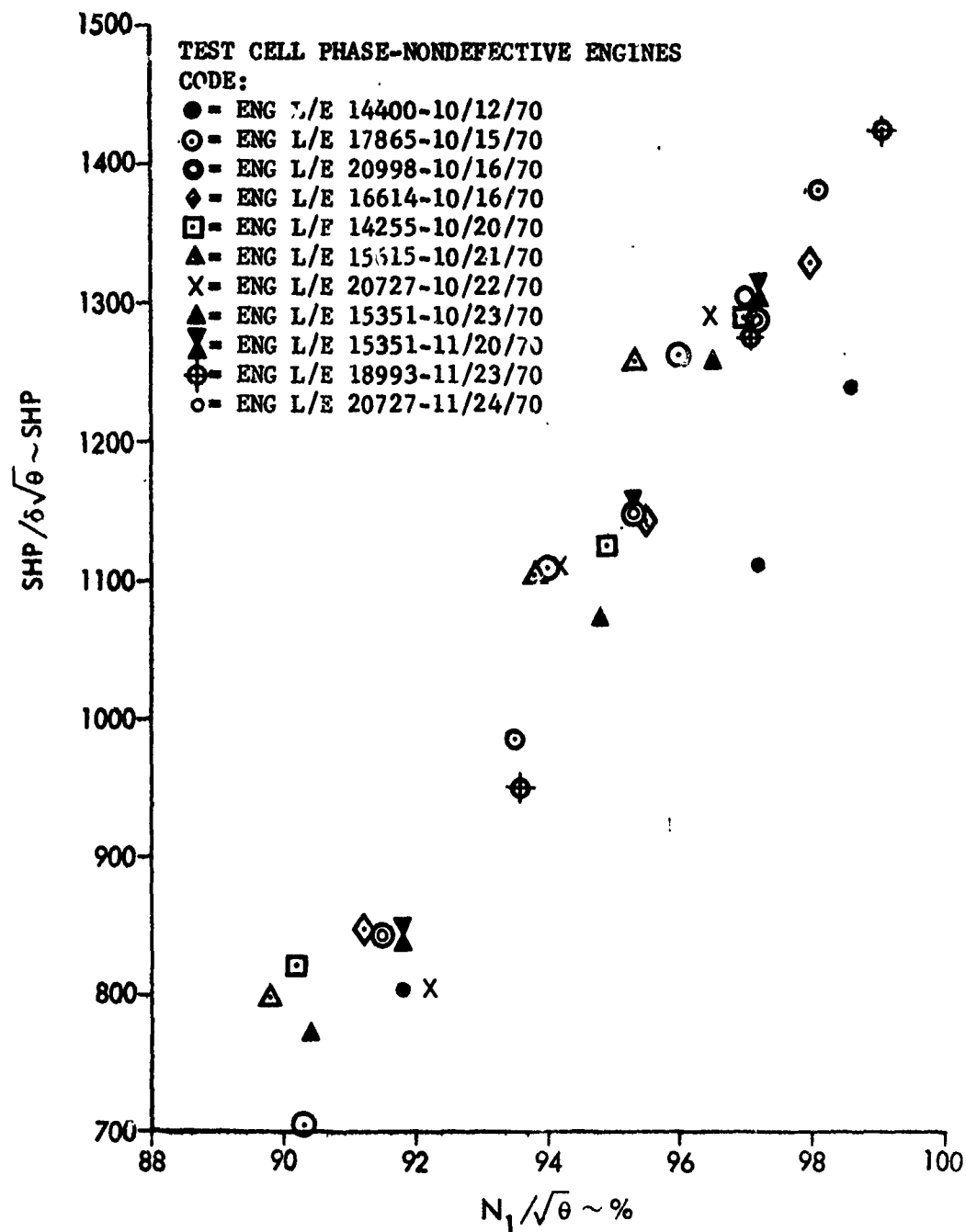


FIGURE 5-16 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

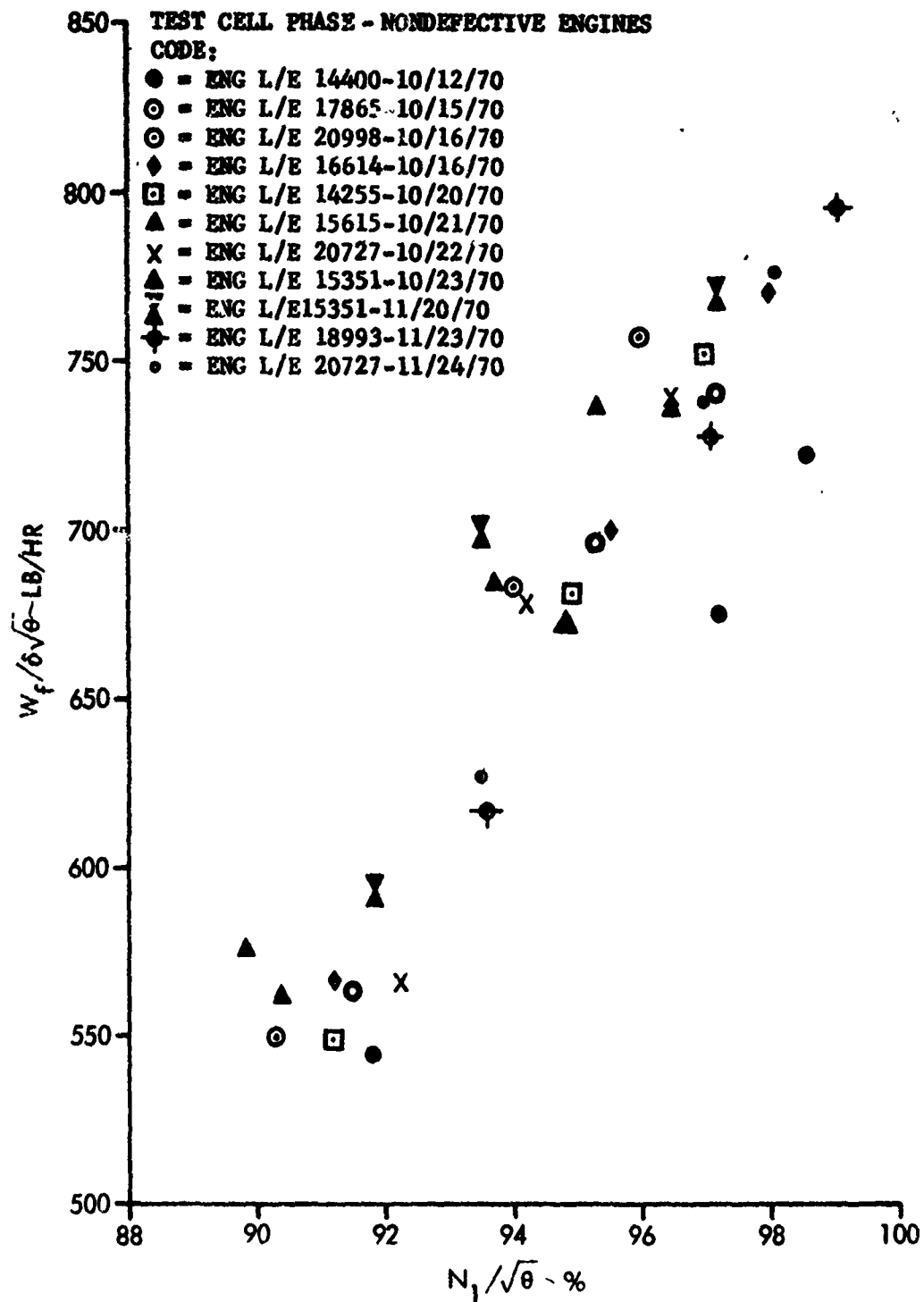


FIGURE 5-17 CORRECTED FUEL FLOW VS CORRECTED  $N_1$  SPEED

# TEST CELL PHASE-NONDEFECTIVE ENGINES

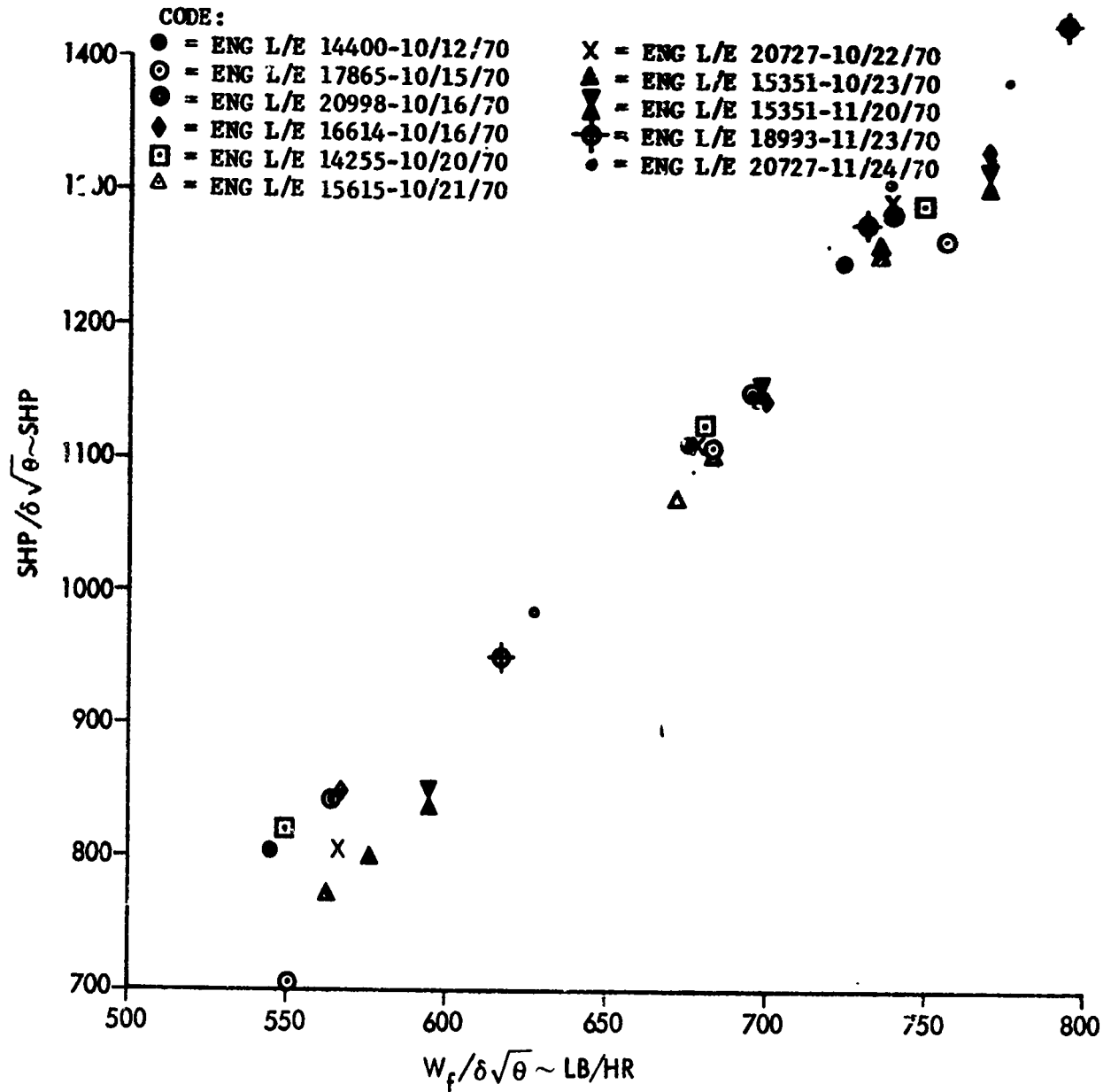


FIGURE 5-18 CORRECTED SHAFT HORSEPOWER VS CORRECTED FUEL FLOW

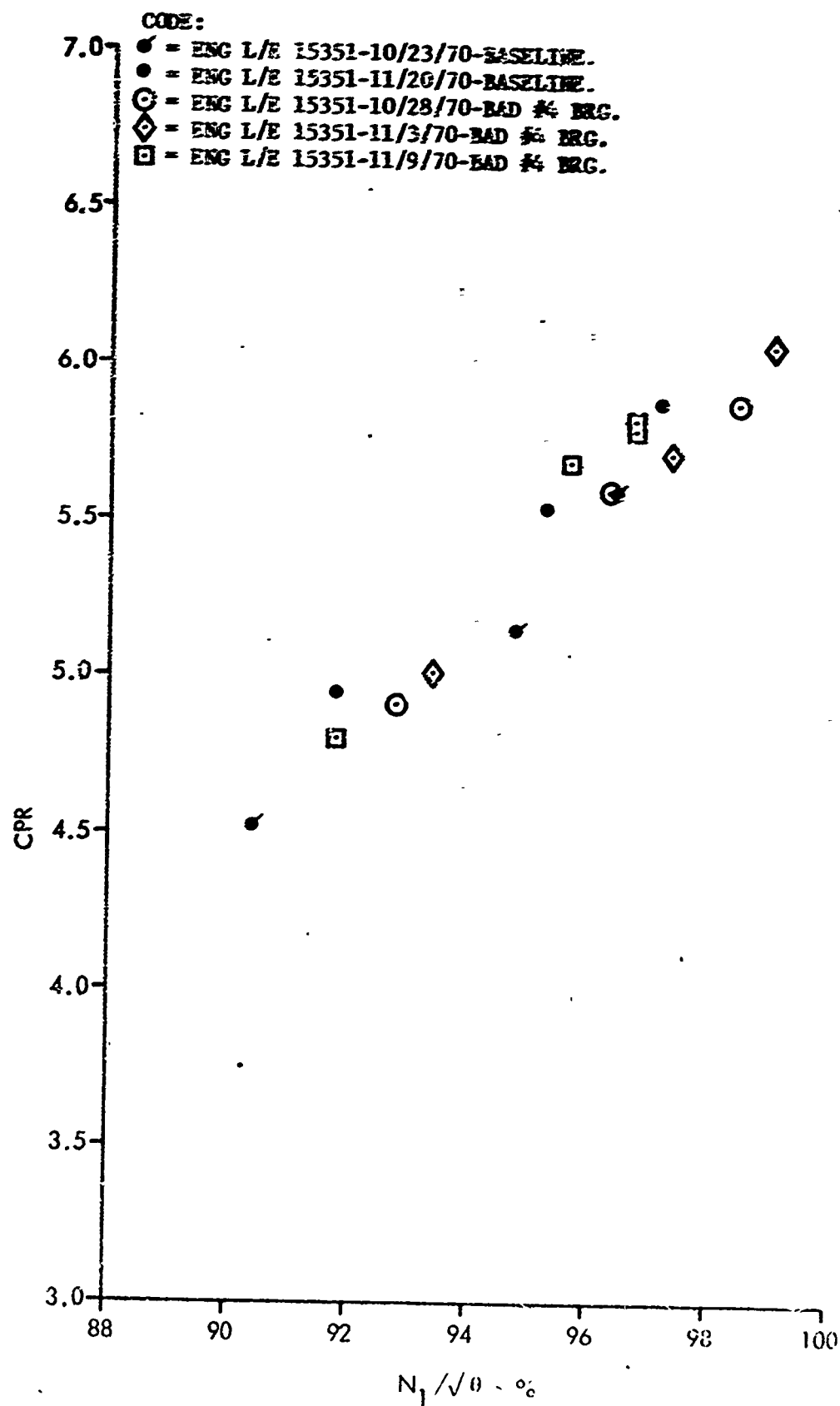


FIGURE 5-19 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

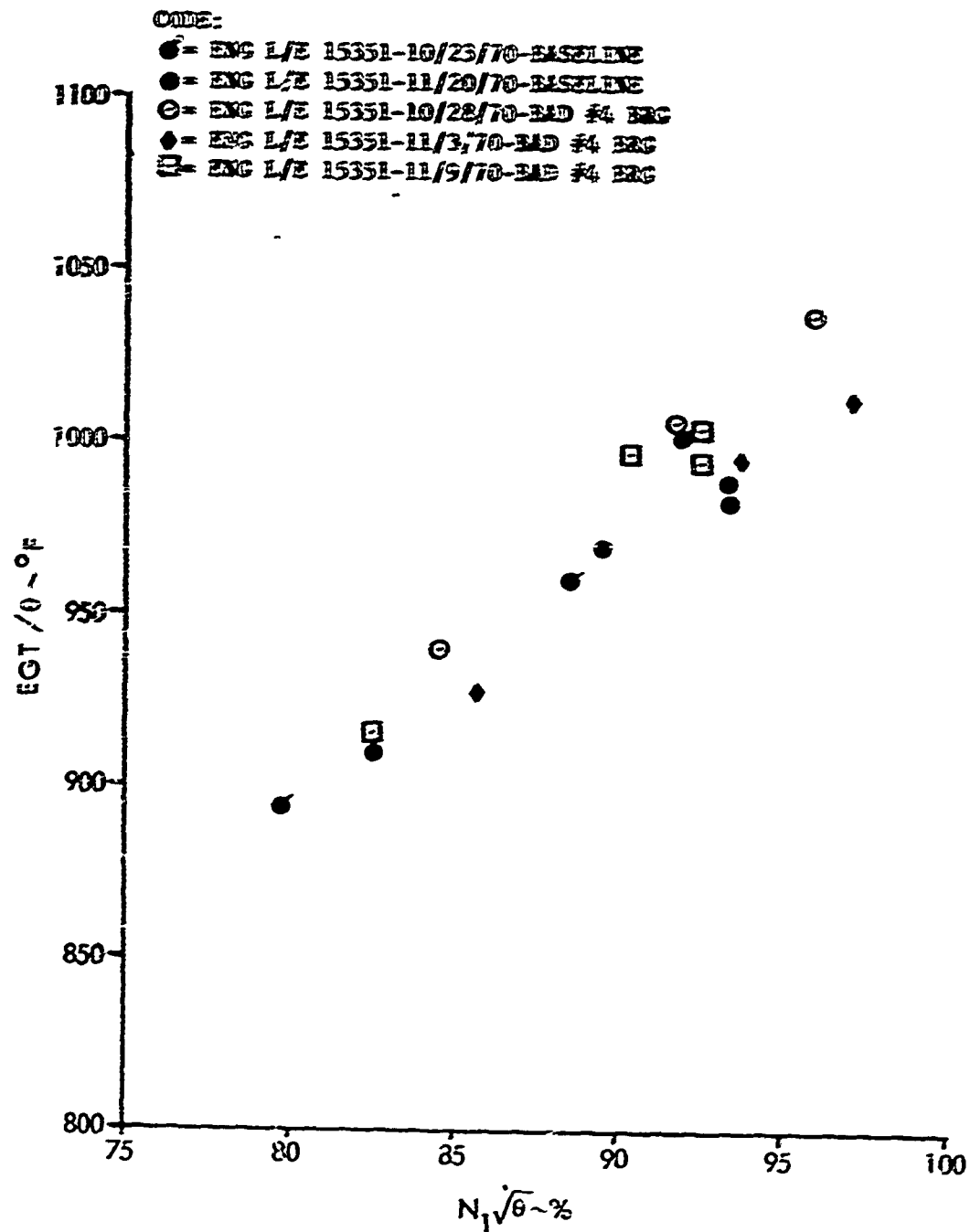


FIGURE 5-20 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

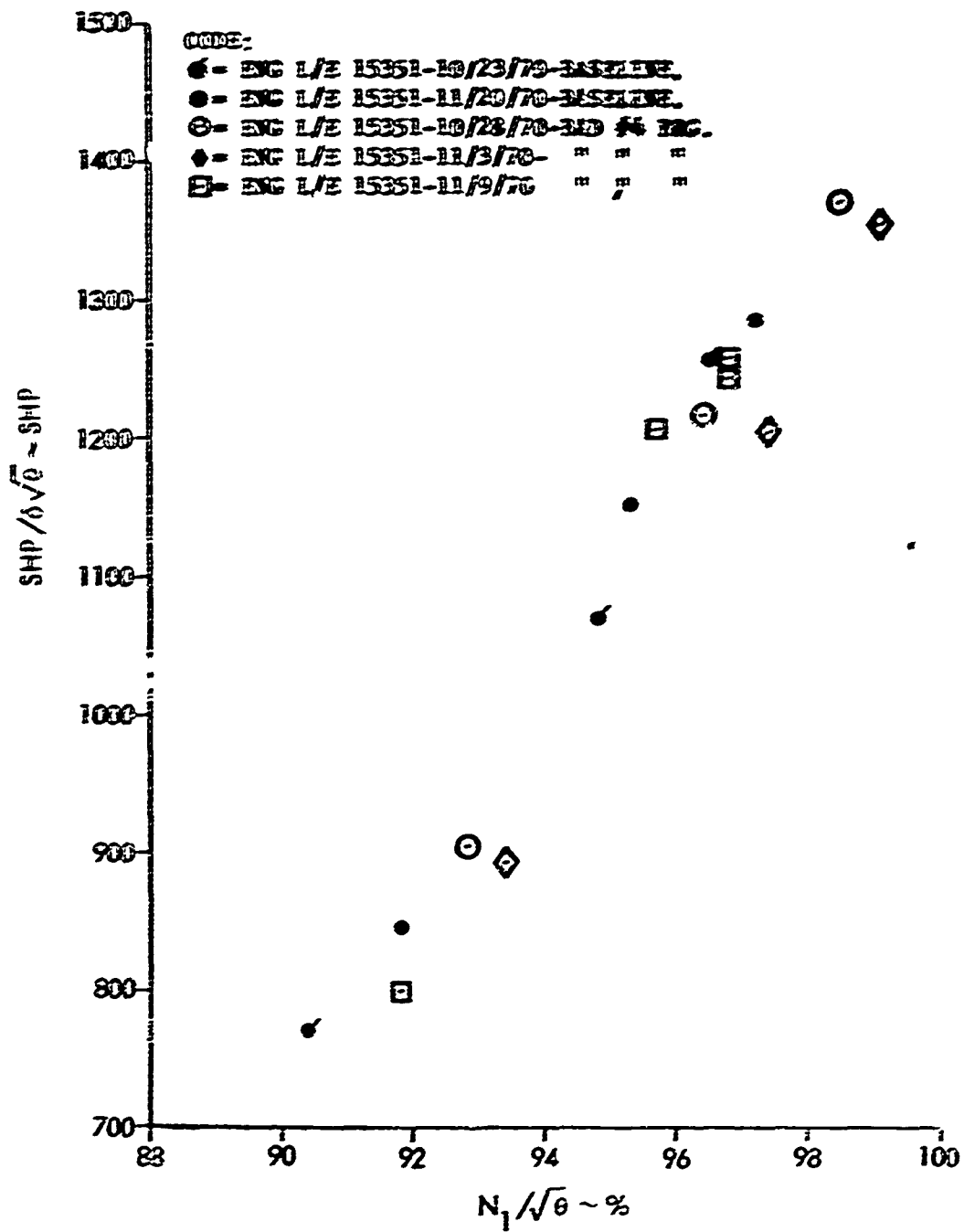


FIGURE 5-21 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

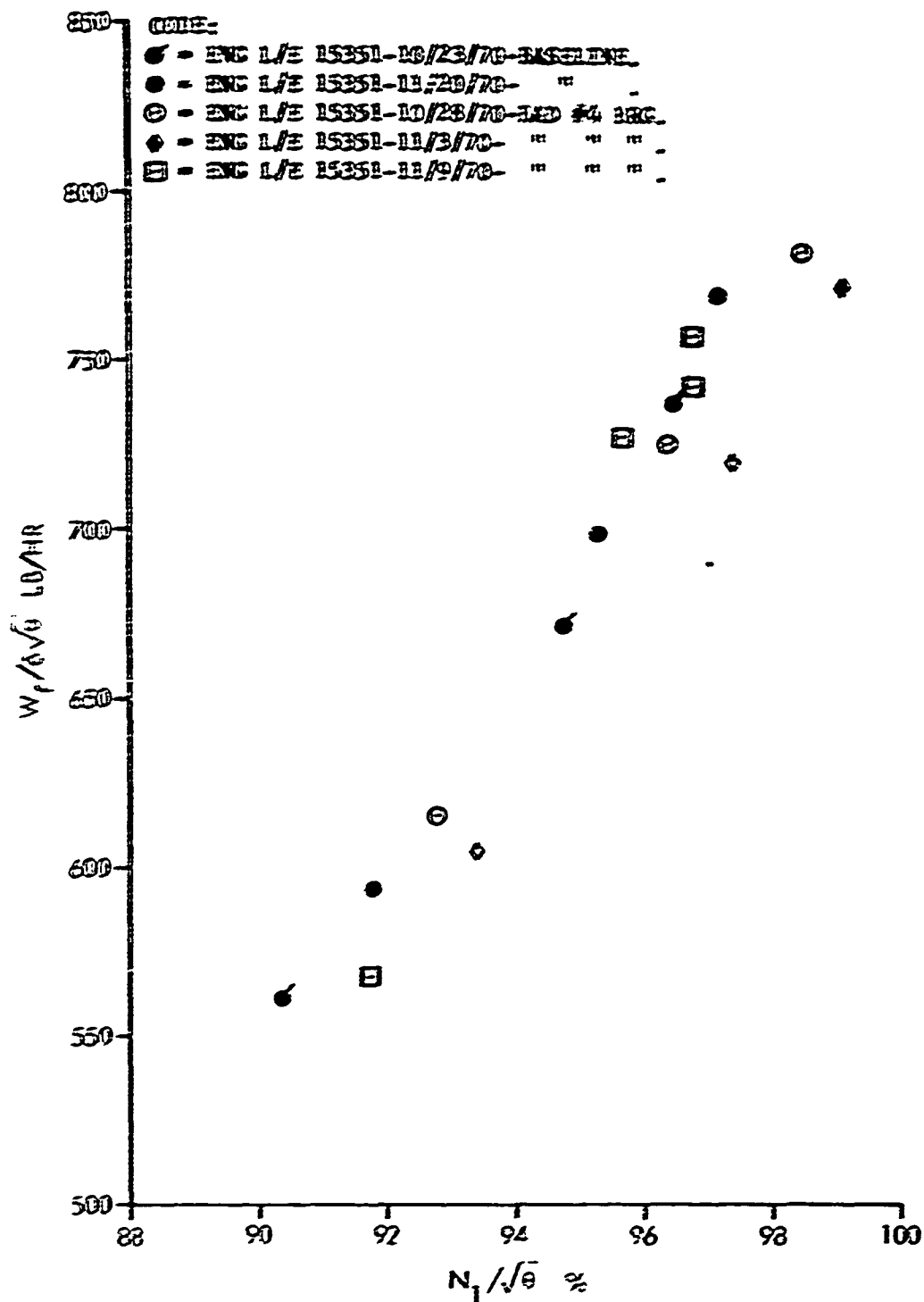


FIGURE 5-22 CORRECTED FUEL FLOW VS CORRECTED  $N_1$  SPEED

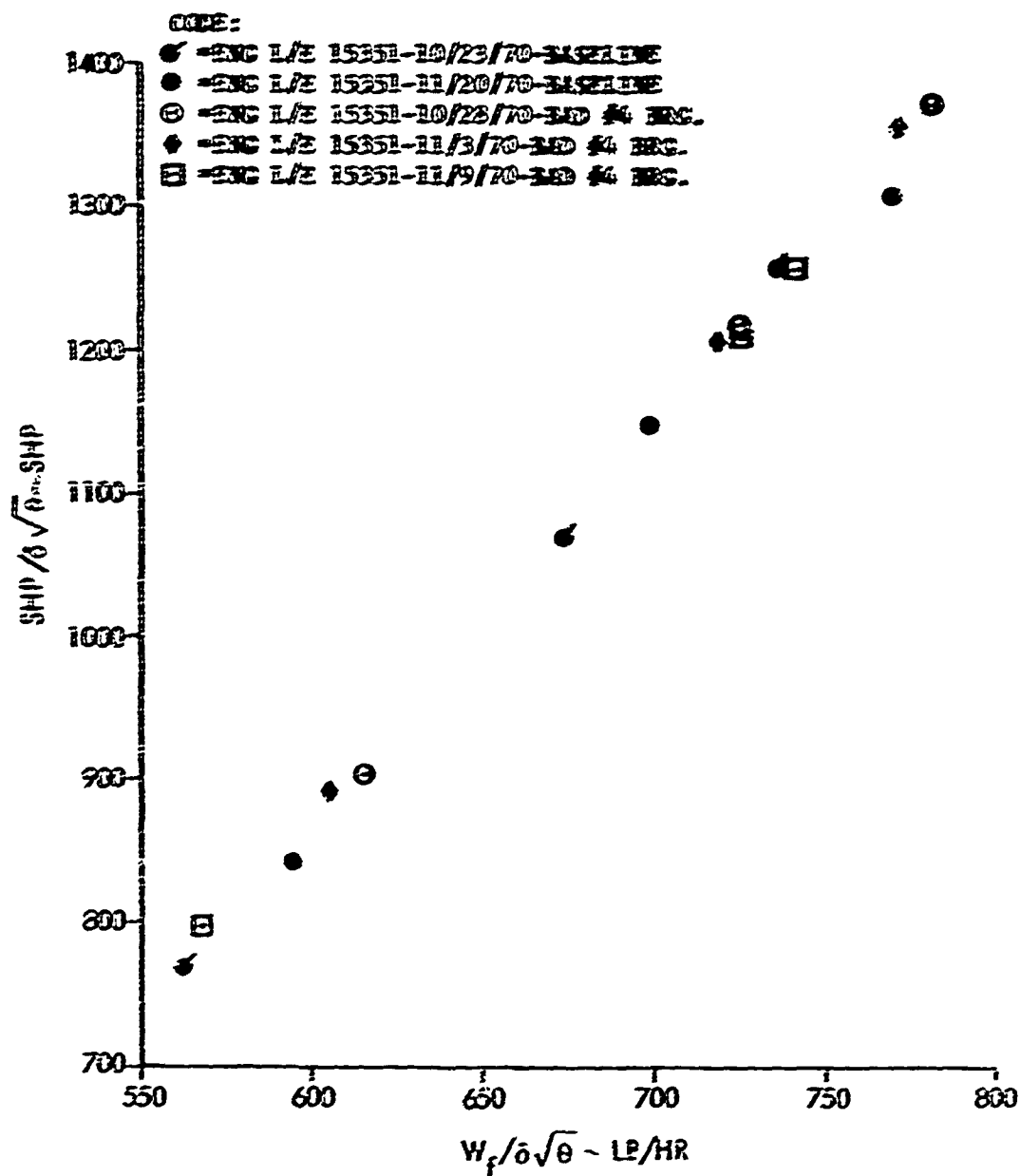


FIGURE 5-23 CORRECTED SHAFT HORSEPOWER VS CORRECTED FUEL FLOW

2) Only significant engine performance changes occurred on the second discrepant number 4 bearing engine run (3 November 1970). Considerably lower shaft horsepower and engine fuel flow, as a function of engine speed, are shown in figures 5-21 and 5-22. The exhaust gas temperatures are also slightly lower than the other defective number 4 bearing engine runs. These factors indicate that the performance changes noted on the second discrepant engine run could not have been attributed to defective bearings but were caused by an engine adjustment of some kind which modified the engine fuel flow schedule. More severely damaged bearings implanted on the third discrepant engine run (9 November 1970) had little effect on engine performance.

A fuel control unit on an engine 1E15351 was adjusted to simulate a misrigged fuel control unit. A normal baseline engine run was conducted at three power settings (military rating, normal rating and 75 percent normal rating), prior to the simulated discrepant fuel control engine run. The following adjustments were made to the fuel control unit for the subsequent engine operations.

- Gas producer rotor ( $N_1$ ) speed high trim set to 101.5 percent
- Power turbine ( $N_2$ ) speed high stop set to 103.5 percent
- Emergency fuel flow adjusted to maximum
- Bleed band adjusted to remain open at military power setting
- Main pressure relief valve setting reset from "2" to "3"
- Inlet guide vane actuator rod shortened two turns
- Clogged fuel filter and strainer installed

Discrepant fuel control engine runs were conducted at military power setting. Additional runs were performed at normal rating settings for an engine with reset main pressure relief valve and fuel control unit containing clogged fuel filter and strainer. During the engine runs no compressor surge was encountered due to misadjusted bleed band, inlet guide vane actuator rod, or main pressure relief valve. Figures 5-24 through 5-28 present the effects of various fuel control adjustments on engine performance. The following table summarizes the approximate engine performance changes for various adjusted fuel control positions at specific power settings (MRP and NRP).

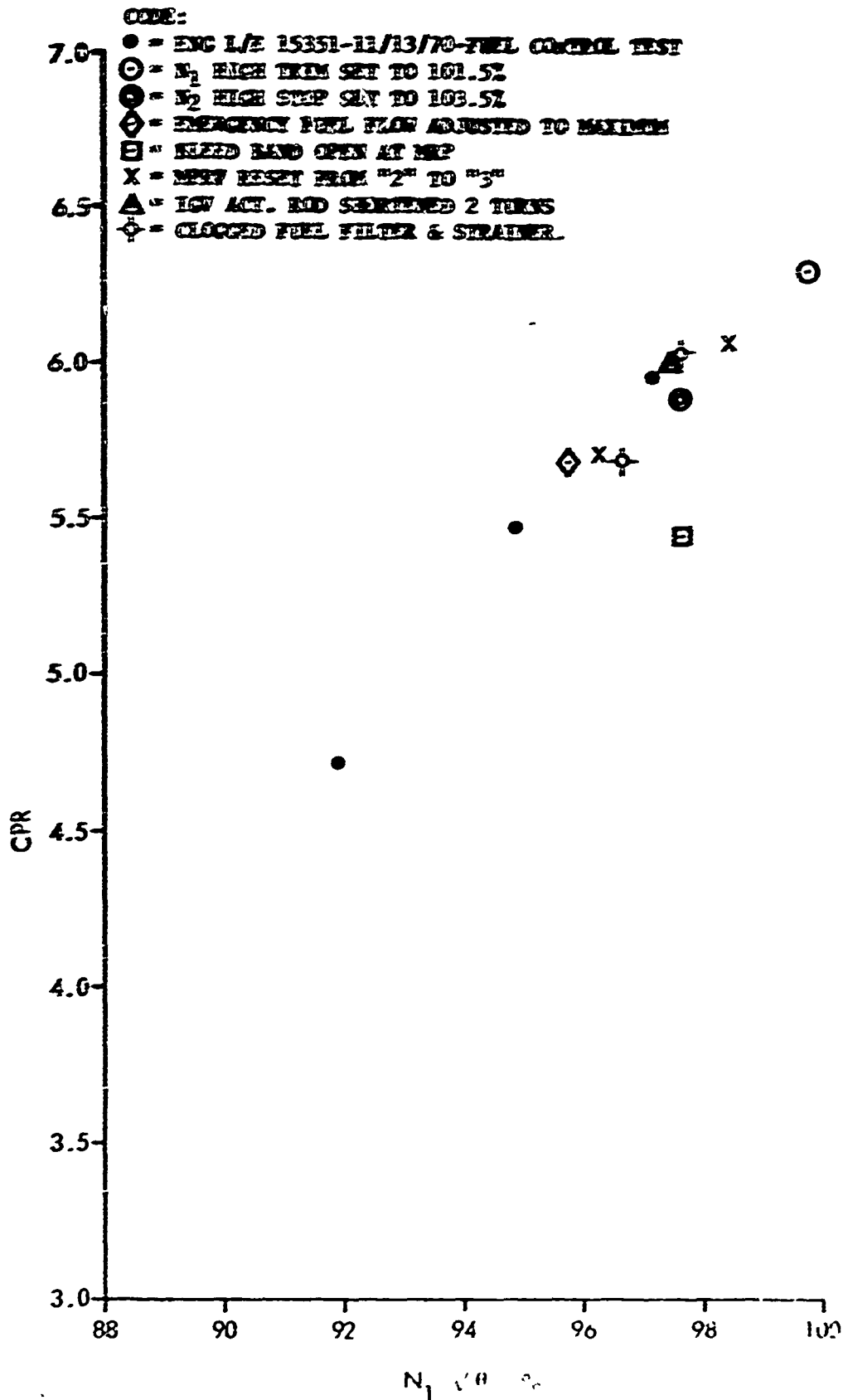


FIGURE 5-24 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

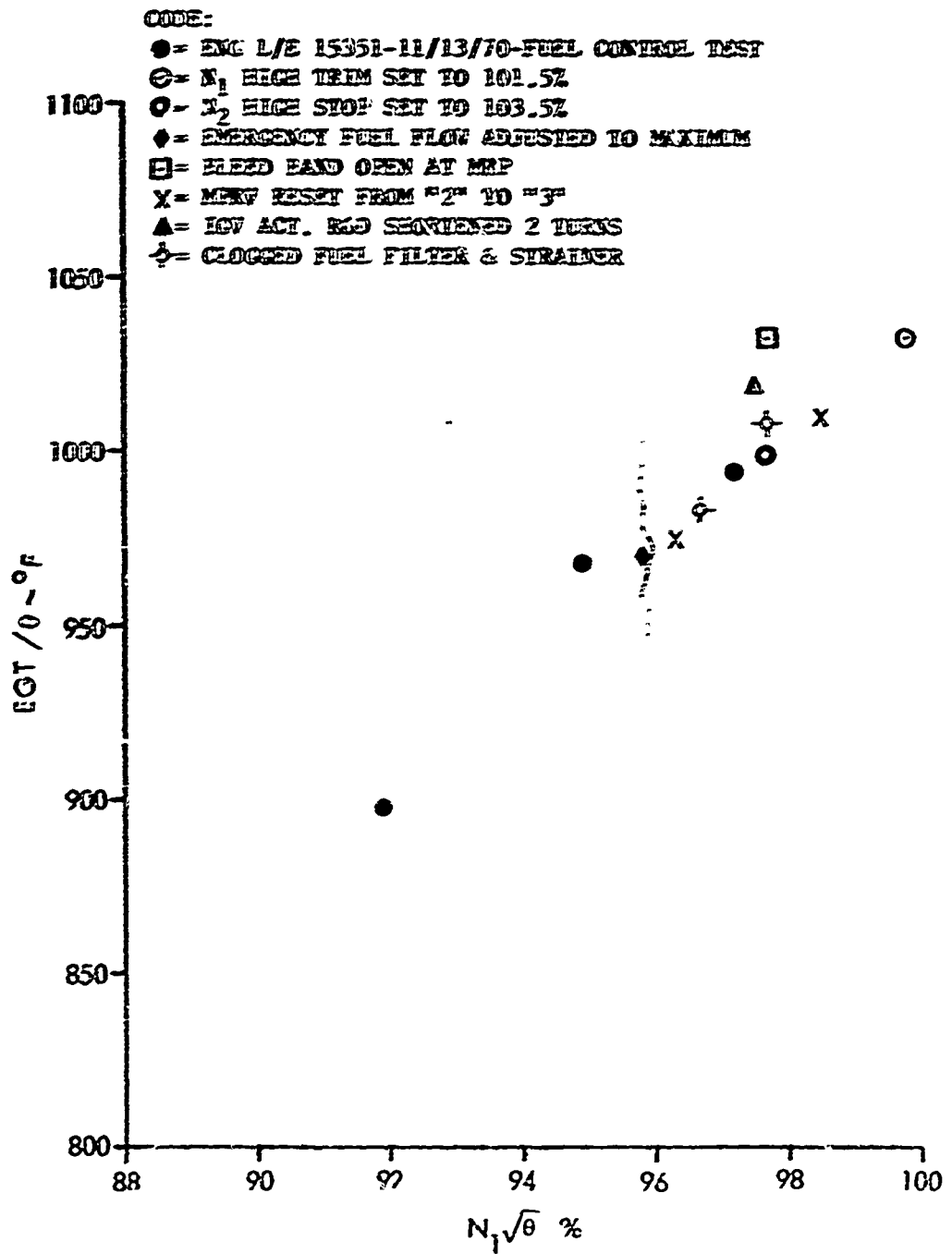


FIGURE 5-25 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

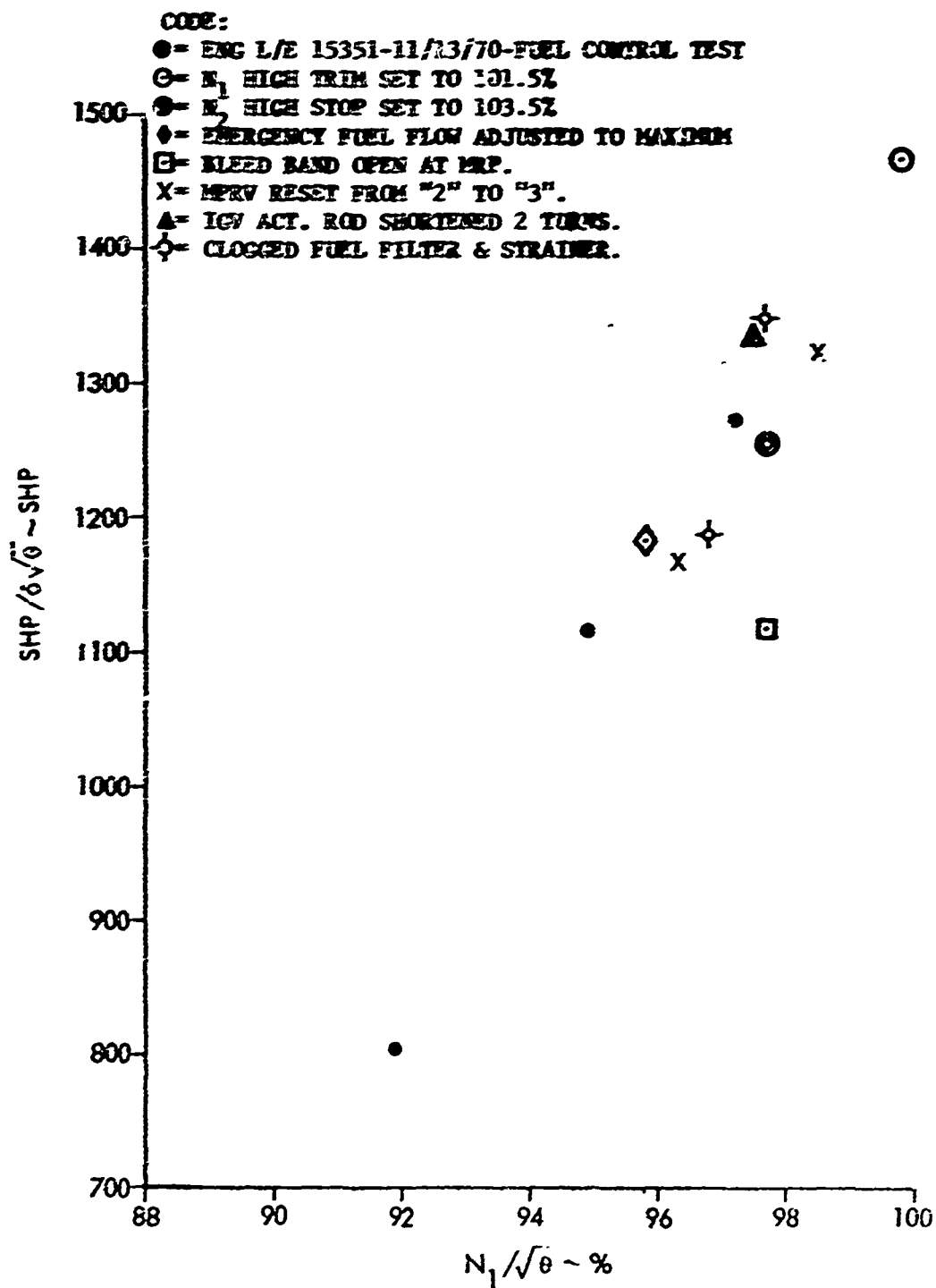


FIGURE 5-26 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

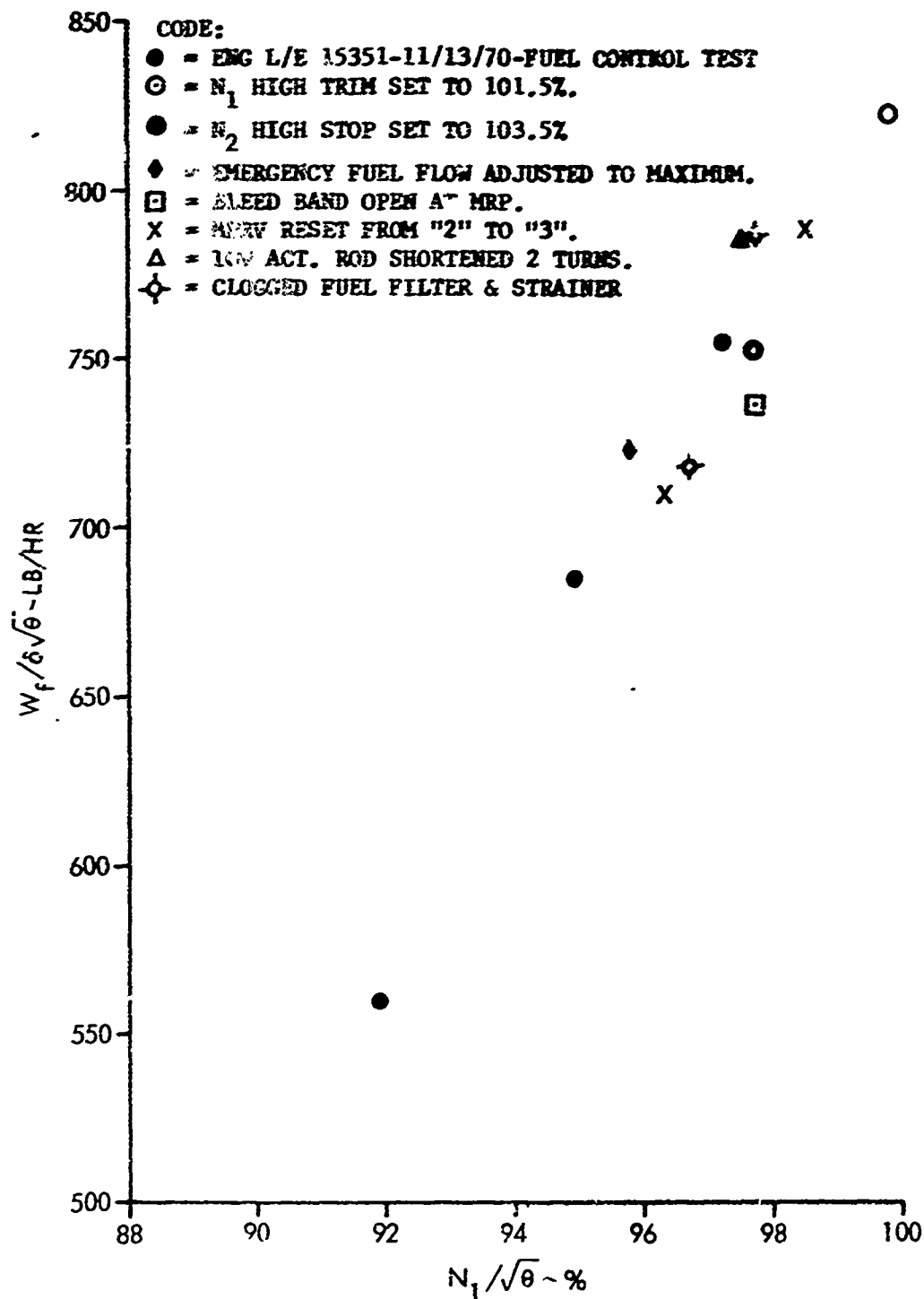


FIGURE 5-27 CORRECTED FUEL FLOW VS CORRECTED  $N_1$  SPEED

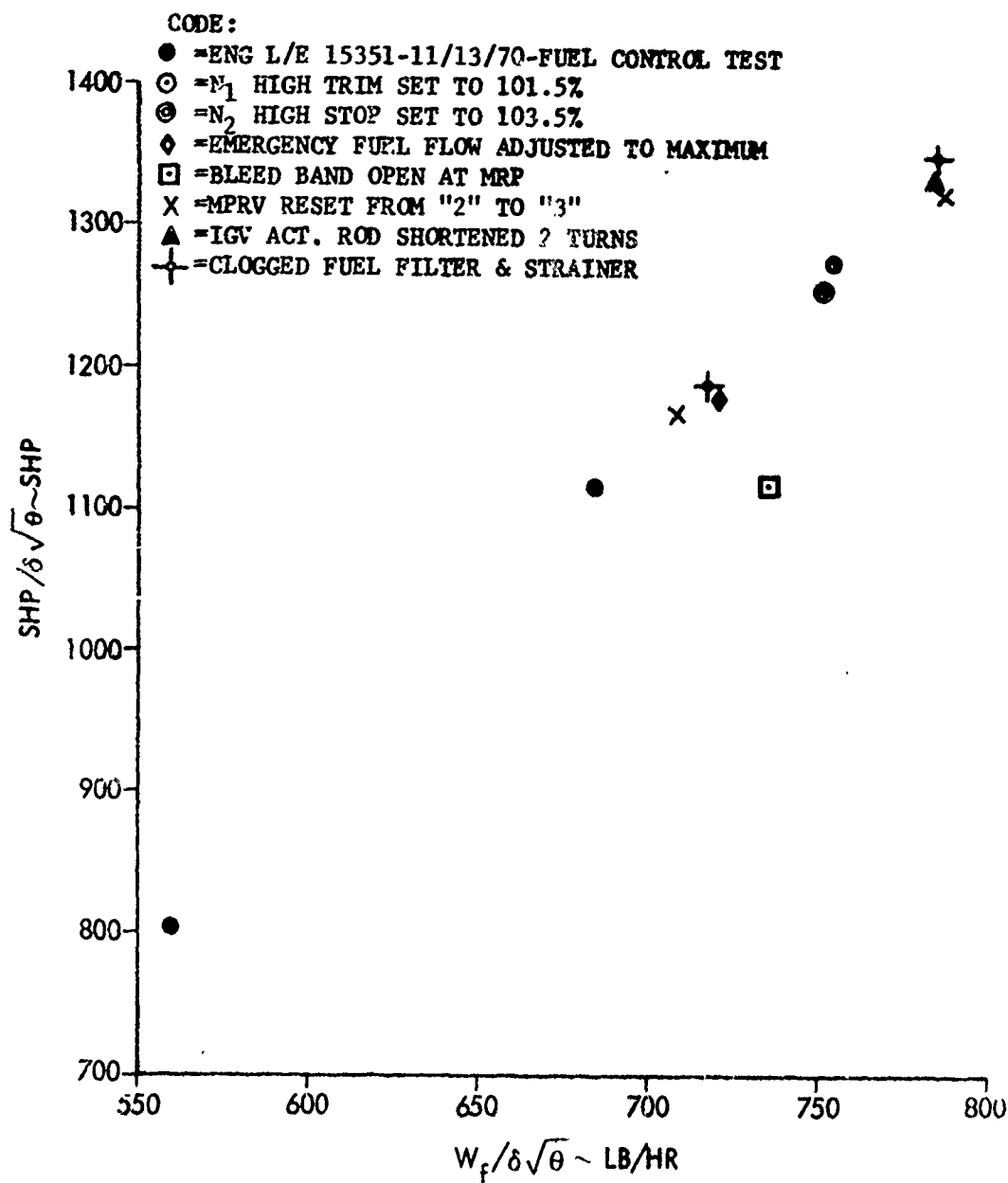


FIGURE 5-28 CORRECTED SHAFT HORSEPOWER VS CORRECTED FUEL FLOW

<u>Fuel Control Condition</u>	<u>Power Setting</u>	<u>N<sub>1</sub> / %</u>	<u>CPR %</u>	<u>SHP/δ√θ %</u>	<u>WF/δ√θ %</u>	<u>EGT/θ %</u>
1	MRP	+3	+5.5	+15	+9	+39
2	MRP	+1	-1	-1	-1	+5
3	MRP	-1.5	-4.5	-7	-4.5	-24
4	MRP	+1	-9.5	-12	-2.5	+39
5	MRP	+1	+2	+4	+4	+15
5	NRP	+2	+4	+5	+3	+7
6	MRP	+1	+1	+5	+4	+25
7	MRP	+1	+1	+6	+4	+14
7	NRP	+2	+4	+6.5	+5	+14

An engine LE18993 was used to test the discrepant gas producer turbine (N<sub>1</sub>) and power turbine (N<sub>2</sub>) nozzles. Two levels of nozzle degradation were evaluated for each turbine assembly. Specific baseline engine performance characteristics were established upon completion of the discrepant turbine nozzle engine runs. Figures 5-29 through 5-33 show the performance values of the five engine runs.

Significant results are:

- a) Engine performance deficiency generally encountered with a damaged N<sub>1</sub> nozzle engine (increased nozzle area) was noted on the first degraded N<sub>1</sub> nozzle engine test (4 November 1970). Decreased compressor pressure ratio is a common symptom for this type of engine damage. Lower shaft horsepower and exhaust gas temperatures are caused by lower engine air pressure and fuel flow.
- b) Subsequent degraded N<sub>1</sub> nozzle engine runs (10 November 1970) showed slight nozzle damage. Essentially, no deficiency in compressor performance was indicated at MRP and NRP settings. Slight increase in compressor pressure ratio at 75 percent NRP indicates slight decrease in N<sub>1</sub> nozzle area. Similar shaft horsepower deficiency was encountered as the previous N<sub>1</sub> nozzle engine test.
- c) Two degraded N<sub>2</sub> nozzle engine runs showed an effect on the compressor performance. The exhaust gas temperature (EGT), engine fuel flow, and shaft horsepower are the engine performance parameters usually affected by degraded N<sub>2</sub> nozzles. Irregular EGT values were obtained on both degraded

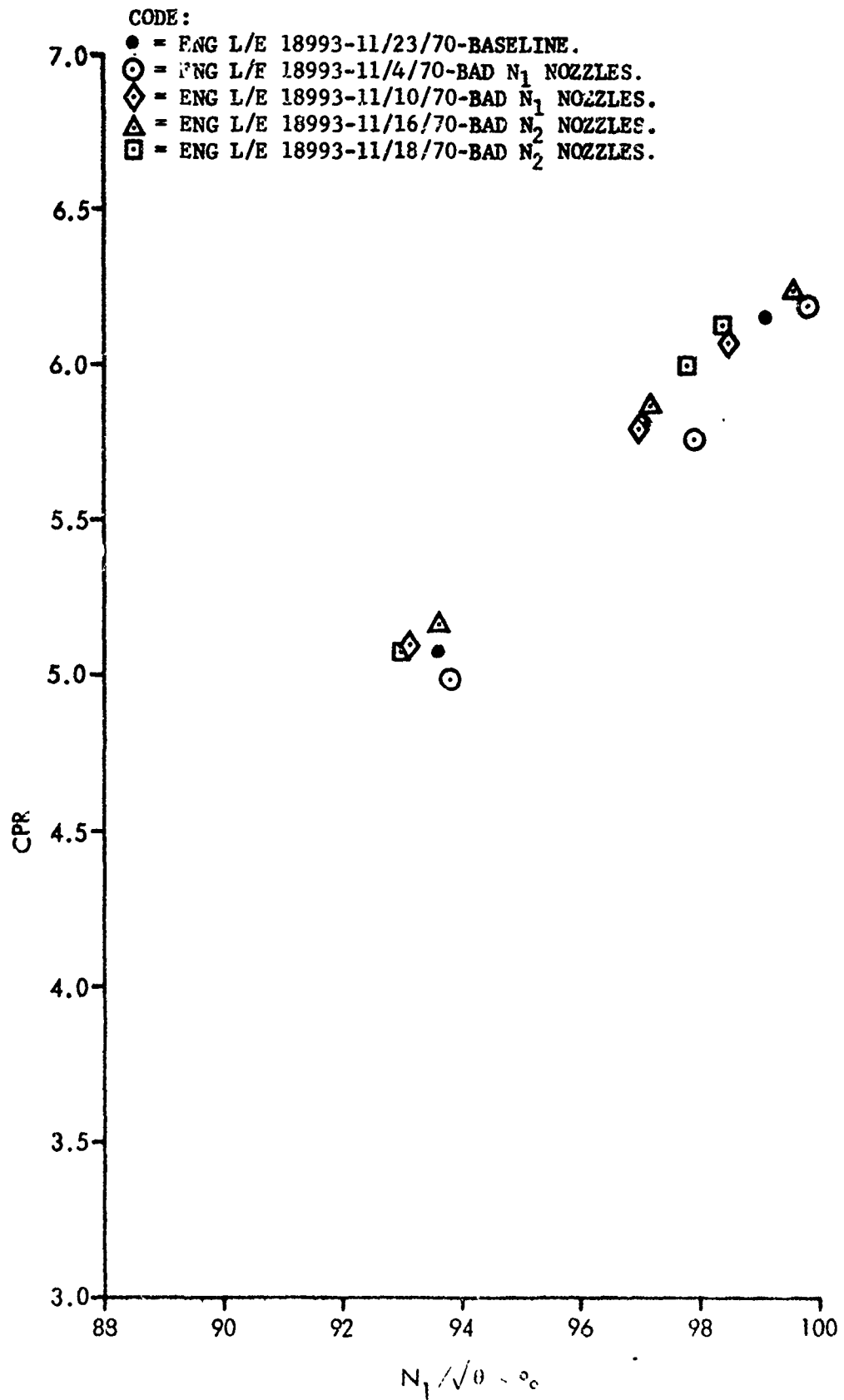


FIGURE 5-29 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

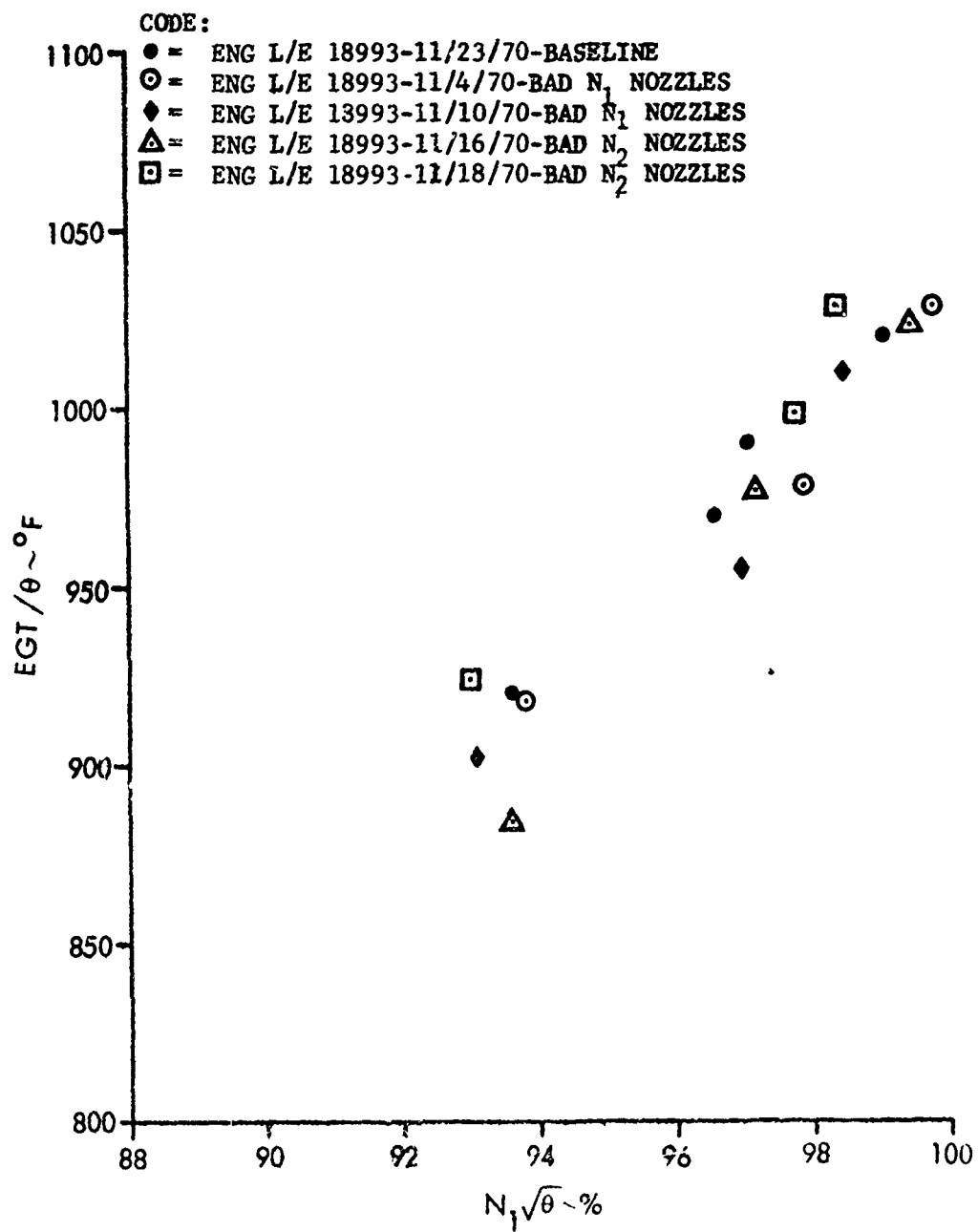


FIGURE 5-30 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

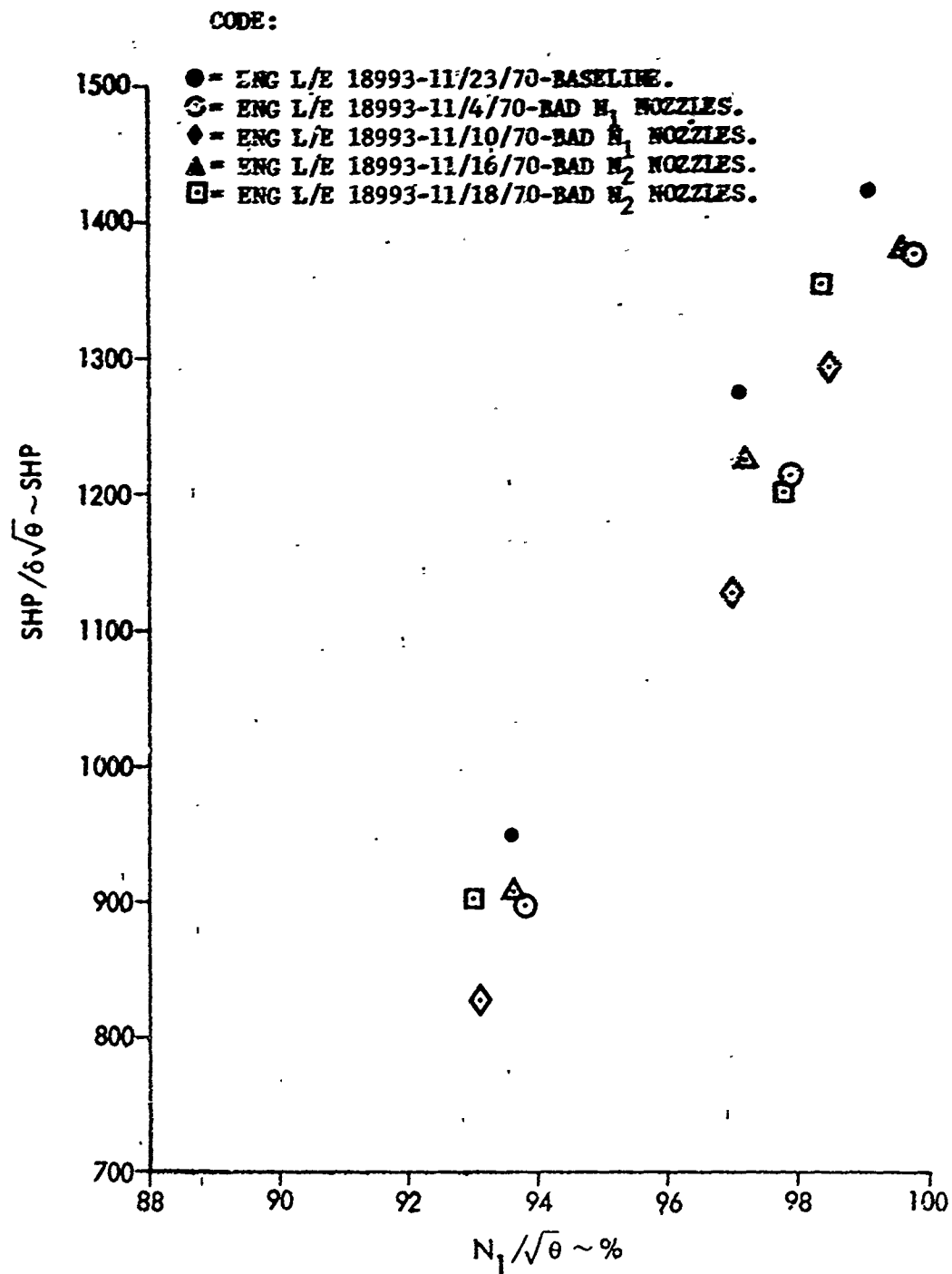


FIGURE 5-31 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

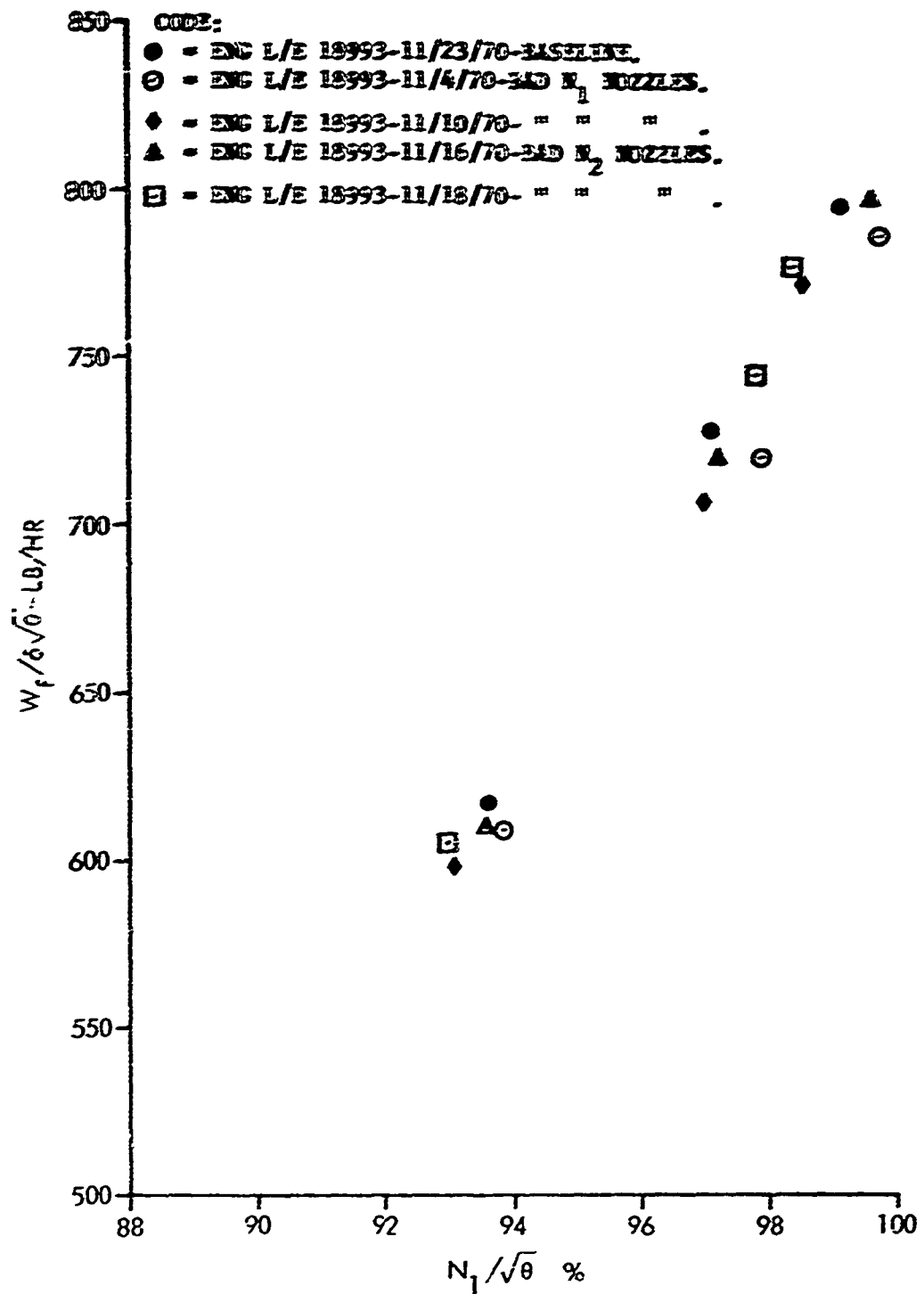


FIGURE 5-32 CORRECTED FUEL FLOW VS CORRECTED  $N_1$  SPEED

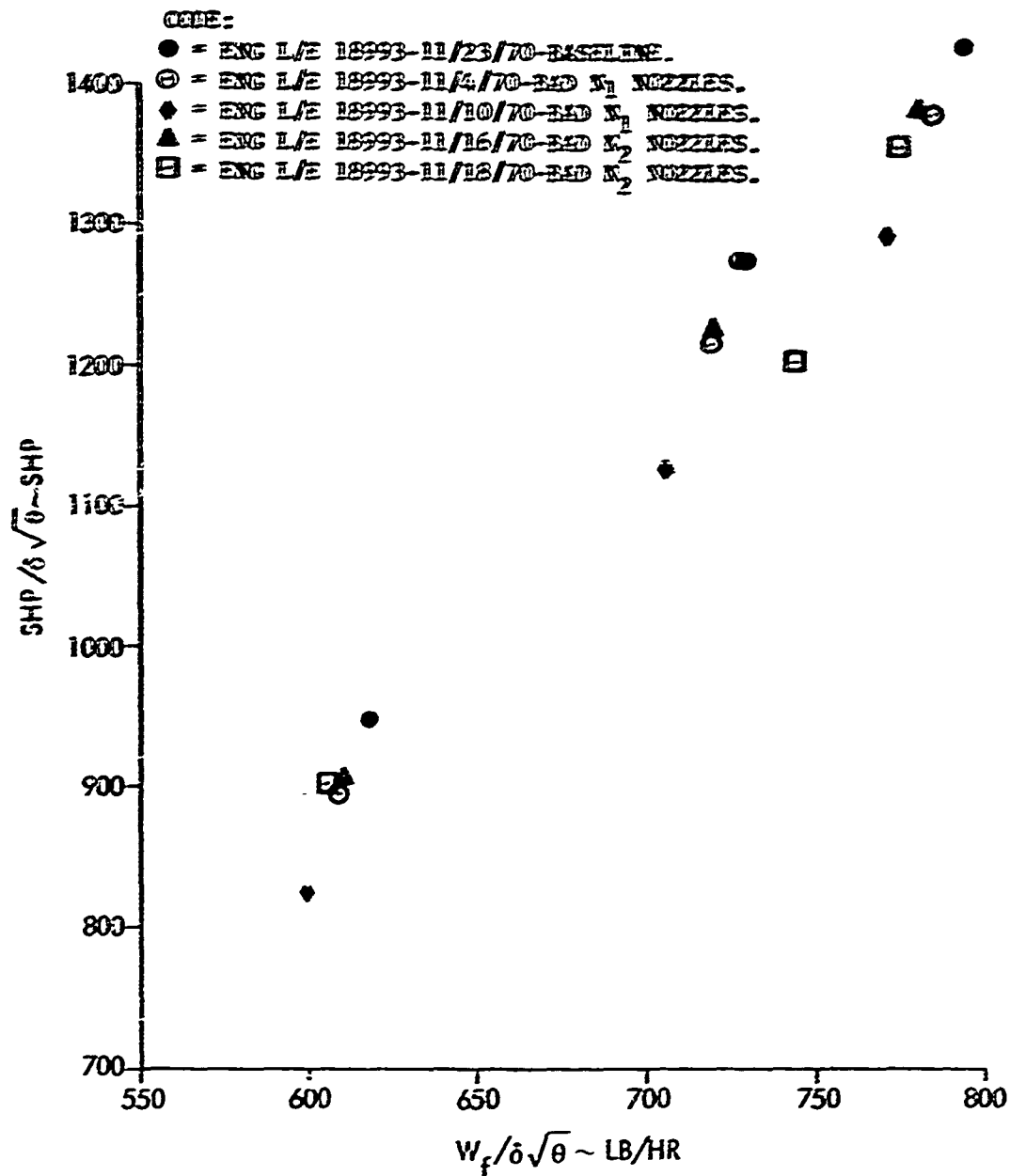


FIGURE 5-33 CORRECTED SHAFT HORSEPOWER VS CORRECTED FUEL FLOW

X<sub>2</sub> nozzle engine runs -- low EGT at 75 percent NRP on the initial run (16 November 1970), and high EGT on the second run (18 November 1970). Engine fuel flow and shaft horsepower were lower than the baseline values on both discrepant X<sub>2</sub> nozzle engine runs.

Figures 5-34 through 5-38 show the effects of discrepant number 2 bearings and compressors on the engine (LE15615) performance. Four defective number 2 bearings, two degraded compressors, and a single baseline engine test run were conducted. Direct engine performance comparison of the discrepant parts and baseline values shown in the figures indicate the following.

- a) The results of the four discrepant number 2 bearing engine tests show significant to moderate performance degradations. Lower engine shaft horsepower and compressor pressure ratio are contrary to the expected engine performance change for the discrepant number 2 bearing samples implanted in the engine. A compressor pressure ratio value at 75 percent NRP setting obtained on the first discrepant number 2 bearing engine run (26 October 1970) is due to bad compressor discharge pressure data.

It appears that an adjustment of some kind may have been made to the engine prior to these discrepant part tests to modify the engine fuel flow schedule (see Figure 5-37). The reduced fuel flow produced the lower shaft horsepower, exhaust gas temperature, and compressor pressure ratio as a function of engine speed.

- b) Two degraded compressor engine runs produced the expected reduction in the compressor performance. Significant shaft horsepower degradations (see Figure 5-36) for the two engine runs are misleading for the same reason presented in the previous discrepant number 2 bearing engine tests. Slight to moderate change in the shaft horsepower and engine fuel flow would have been expected for the selected degraded compressor samples. Figure 5-35 shows that the EGT values for the degraded compressor engine are lower than the baseline EGT trend which is contrary to the normal indication of a compressor damage. Generally, higher EGT would be expected due to reduction in engine air flow caused by compressor damage.

Figures 5-39 through 5-43 show the effects of discrepant number 3 bearings and power turbine on the engine (LE20727) performance. Two nondiscrepant baseline engine runs were conducted before and after the degraded engine runs.

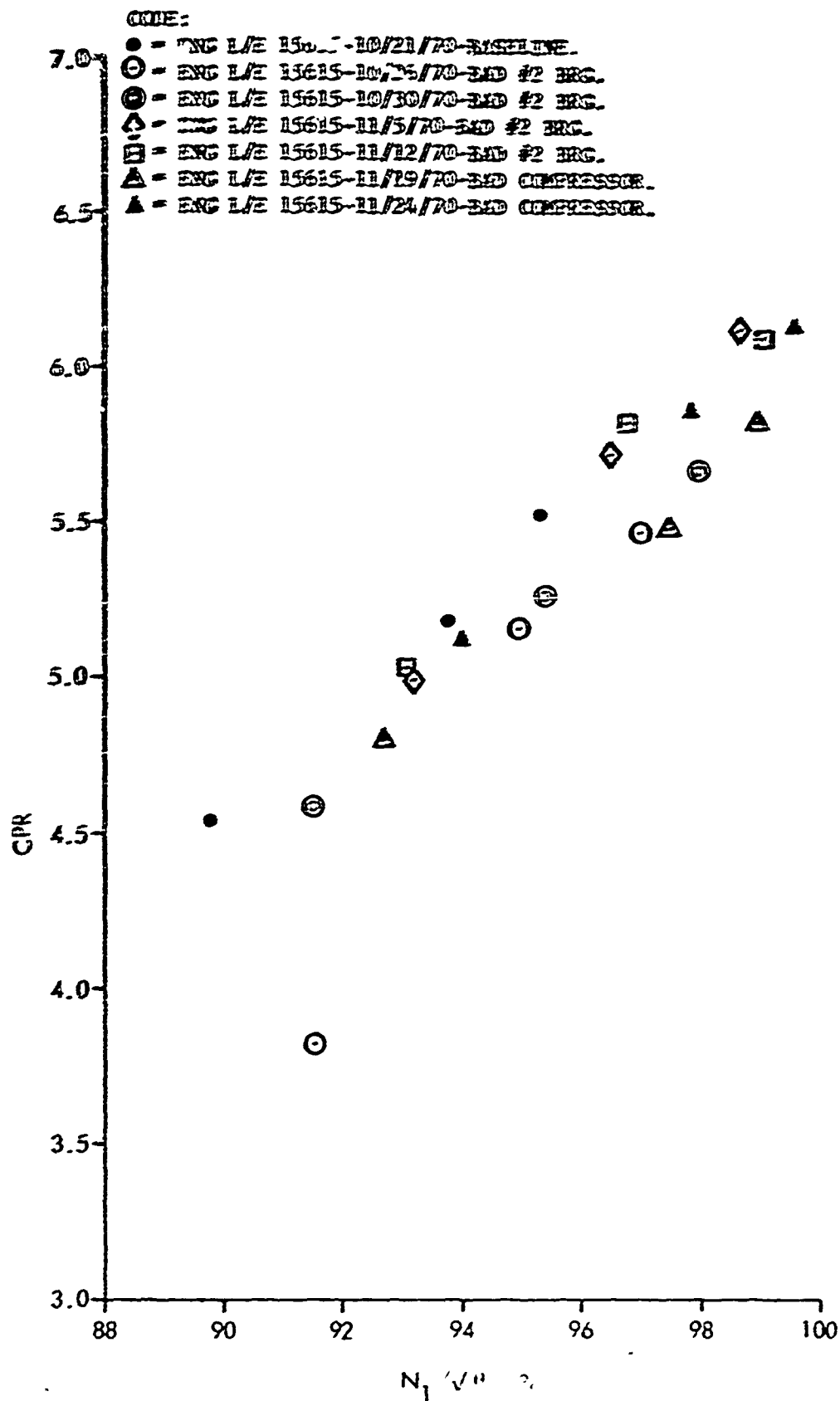


FIGURE 5-34 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

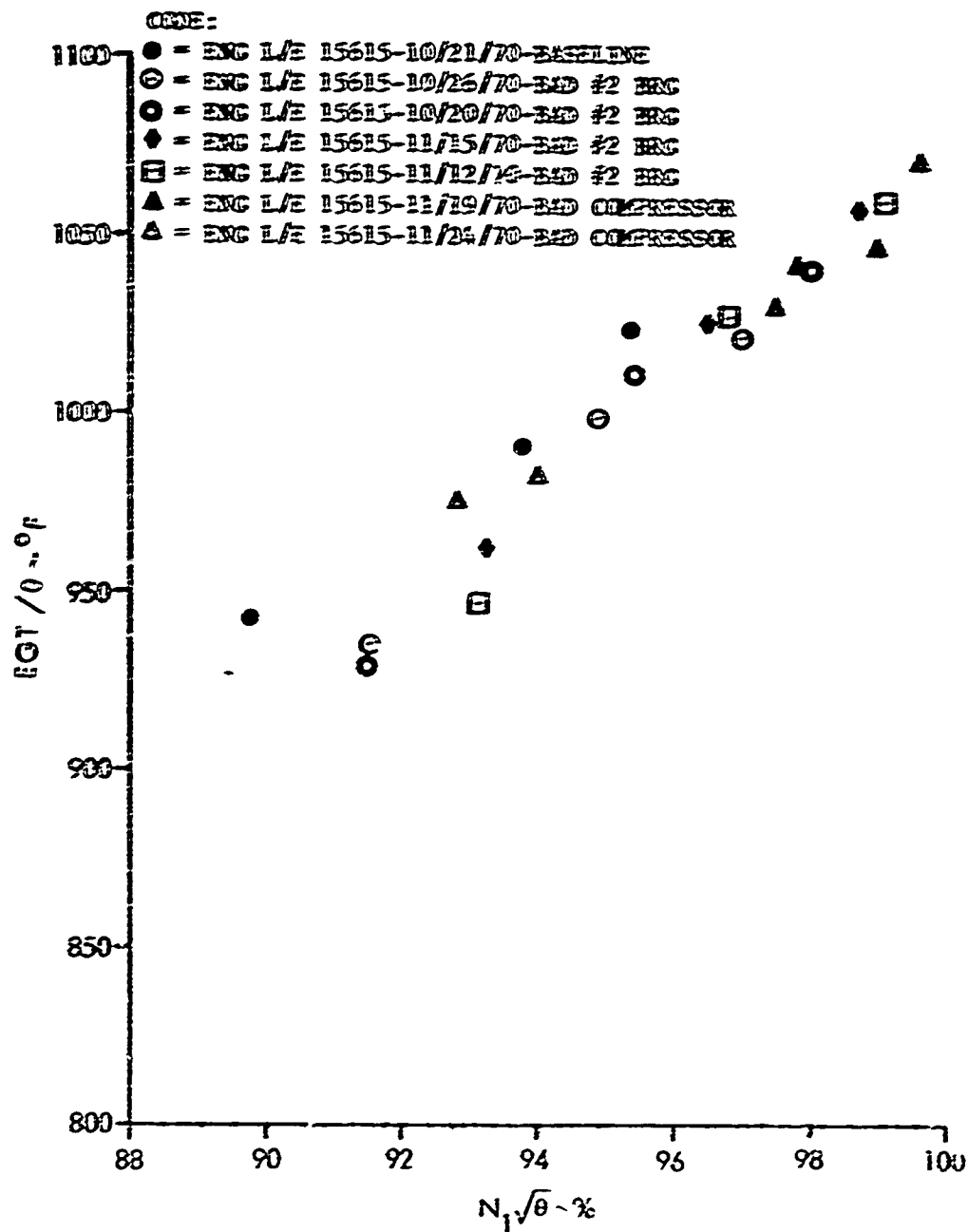


FIGURE 5-35 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

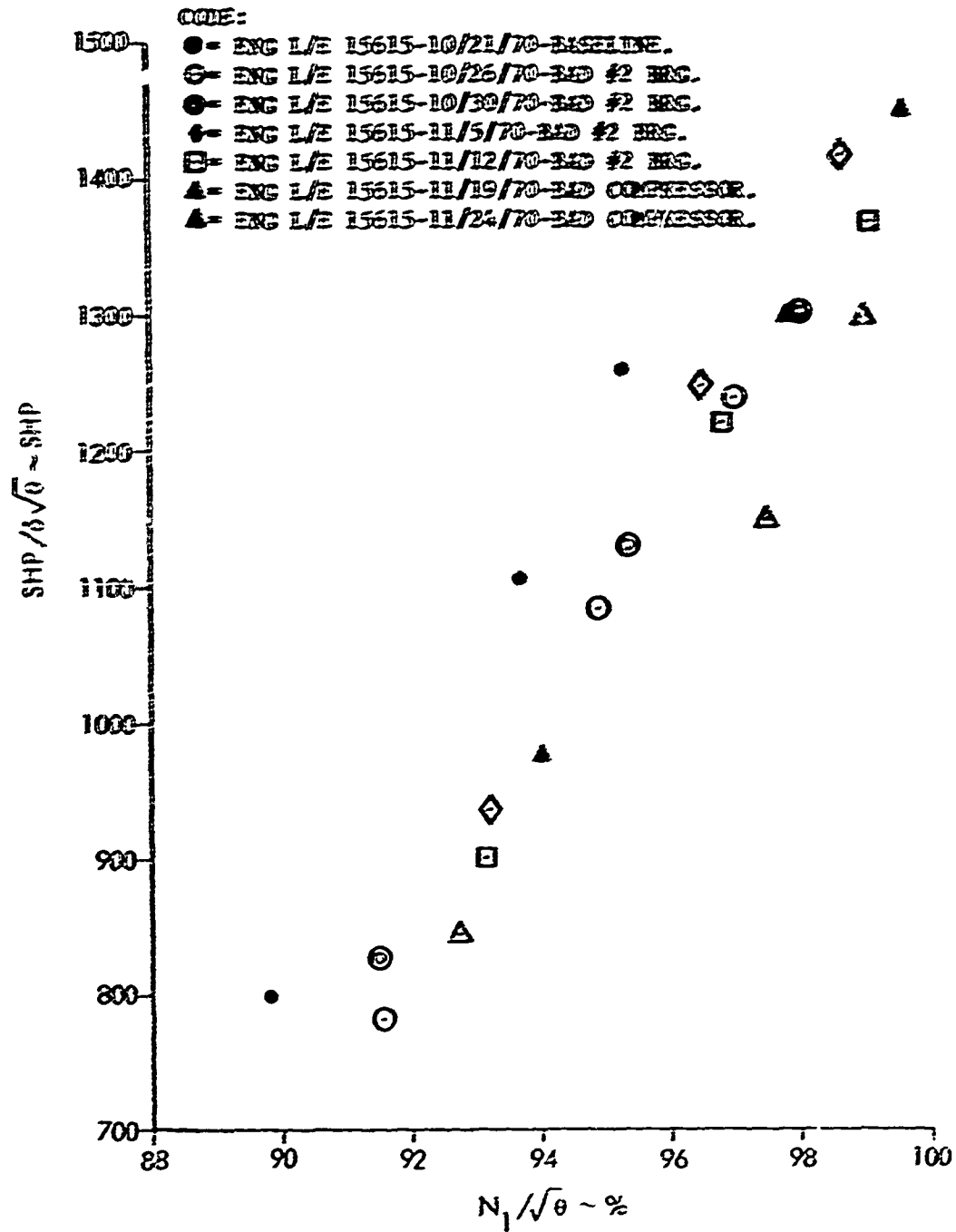


FIGURE 5-36 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

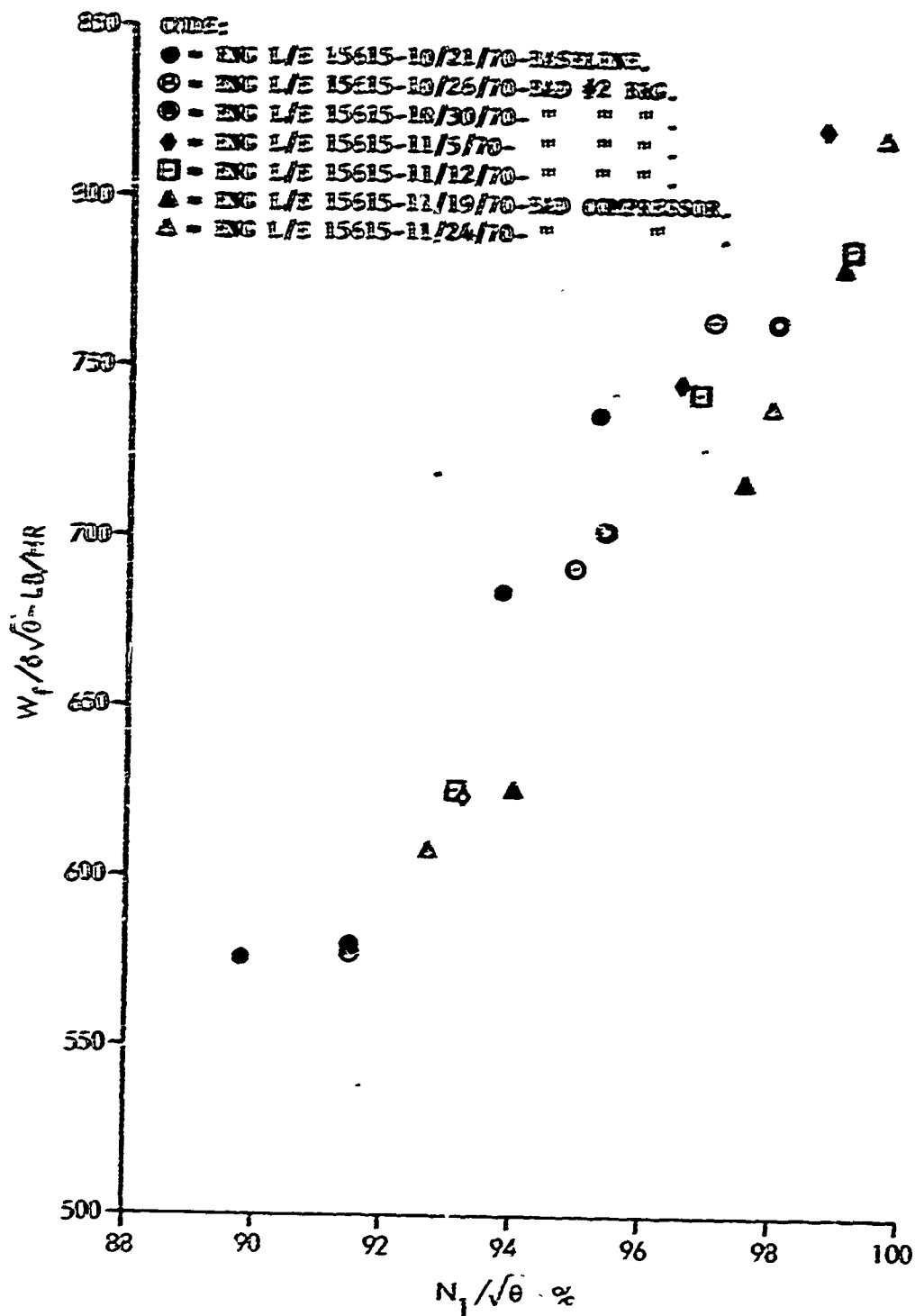


FIGURE 5-37 CORRECTED FUEL FLOW VS CORRECTED  $N_1$  SPEED

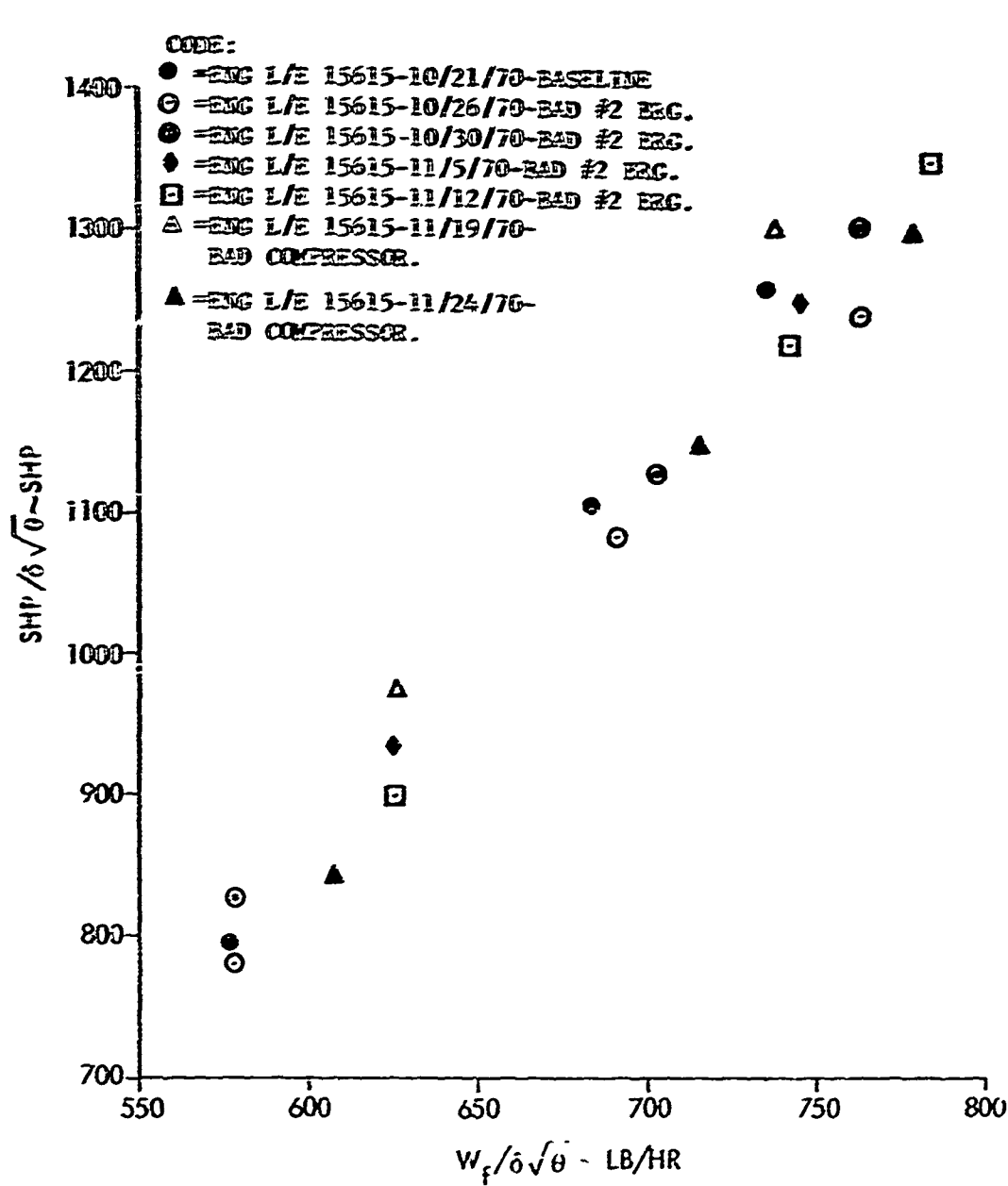


FIGURE 5-38 CORRECTED SHAFT HORSEPOWER VS CORRECTED FUEL FLOW

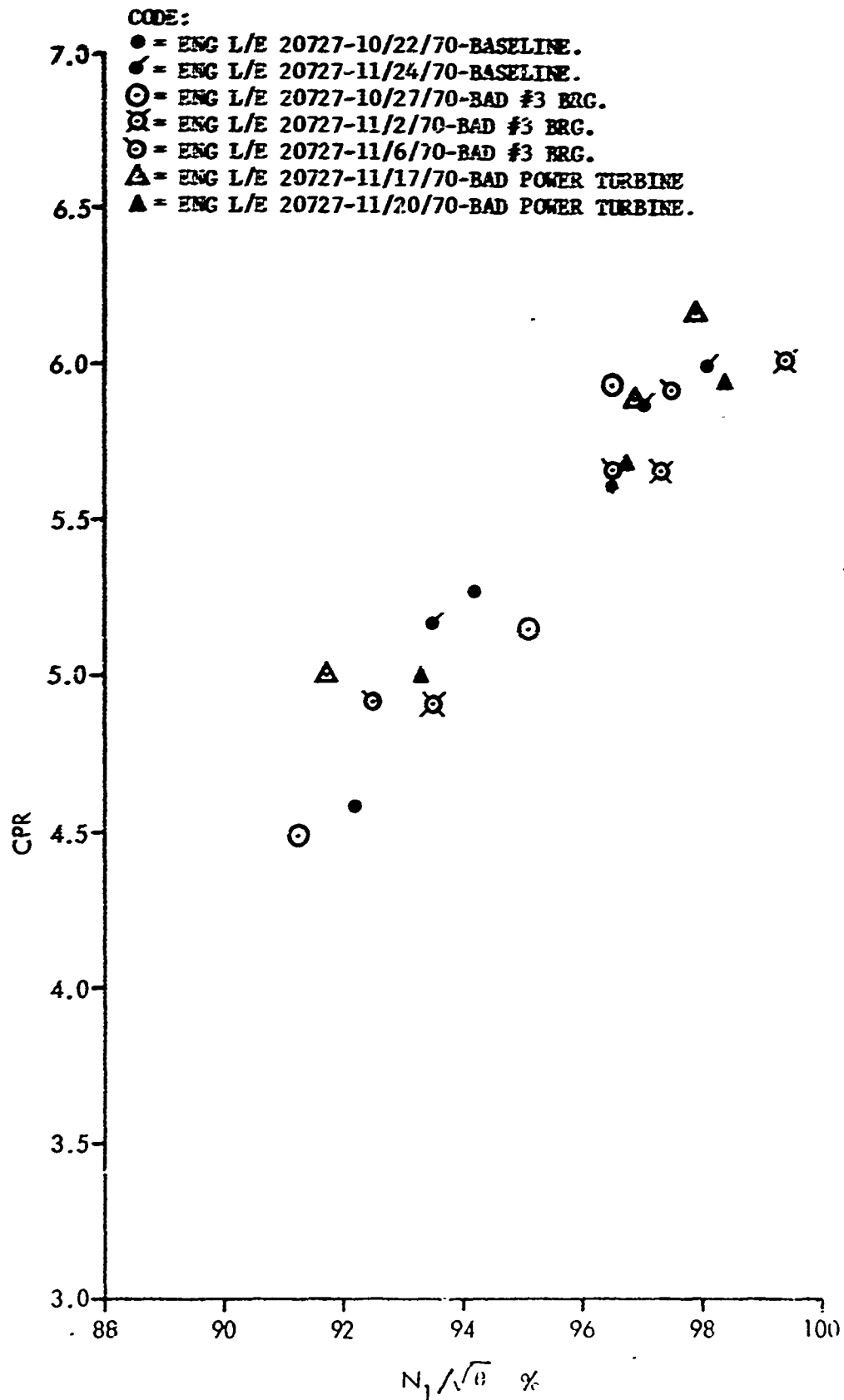


FIGURE 5-39 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

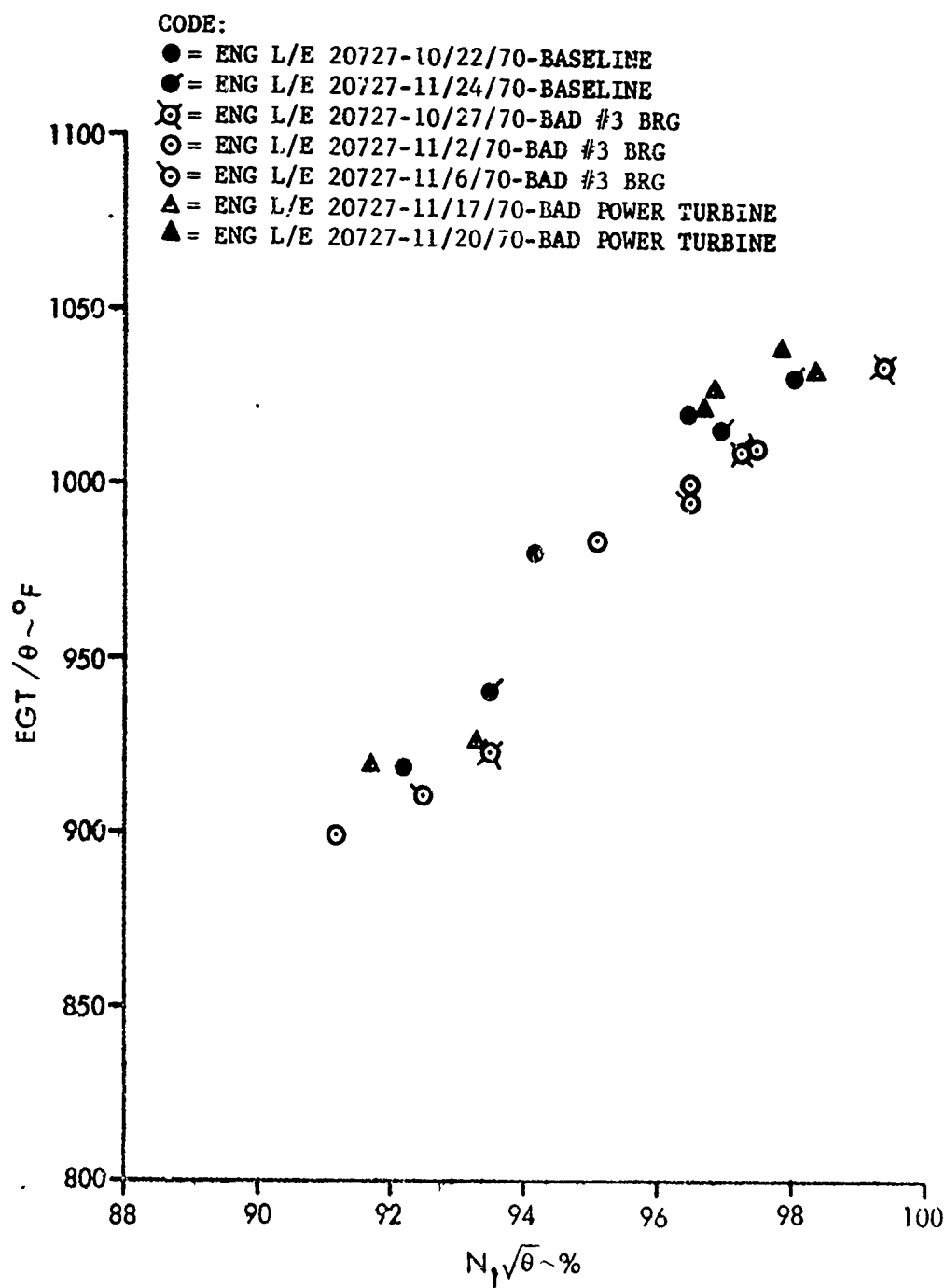


FIGURE 5-40 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

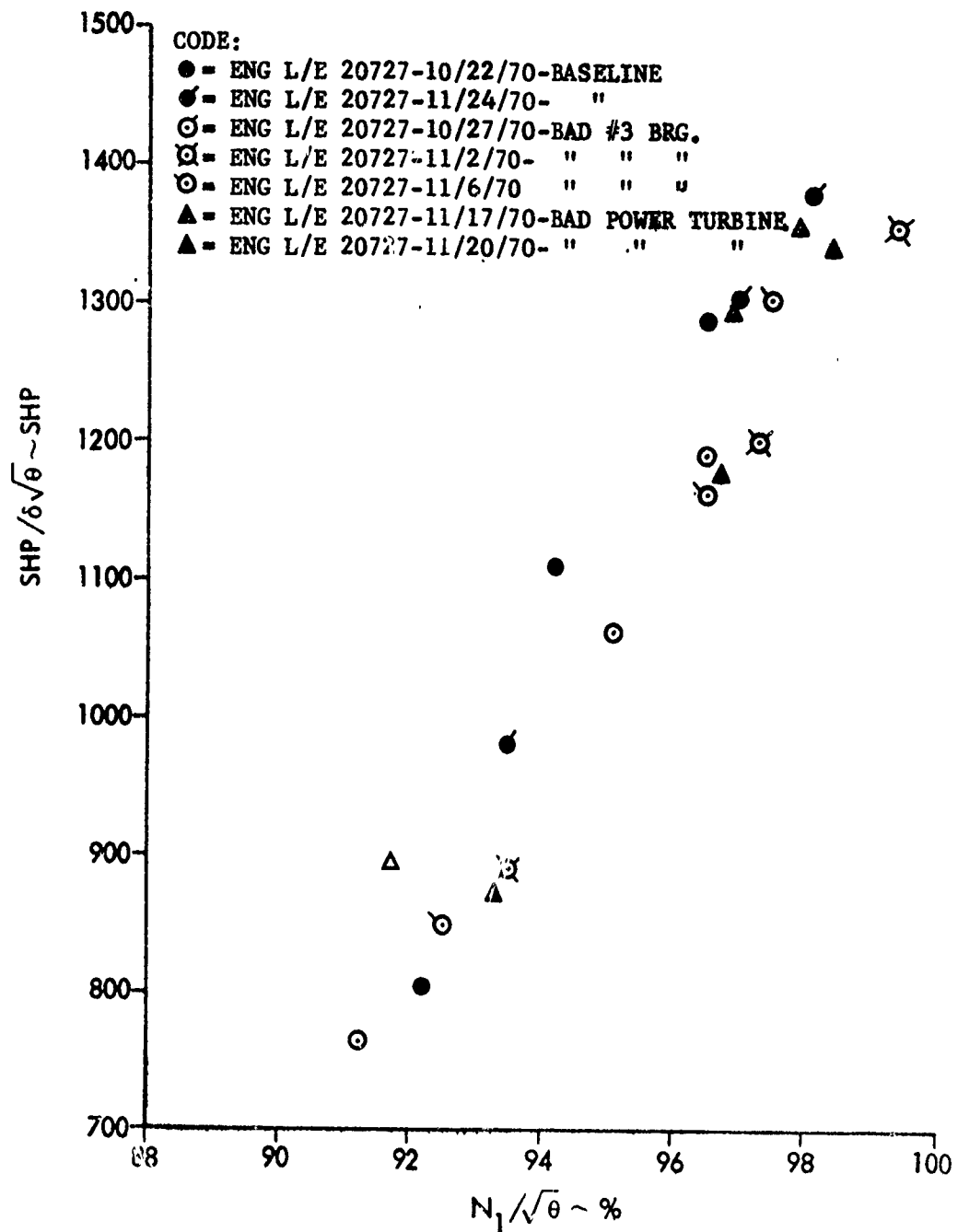


FIGURE 5-41 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

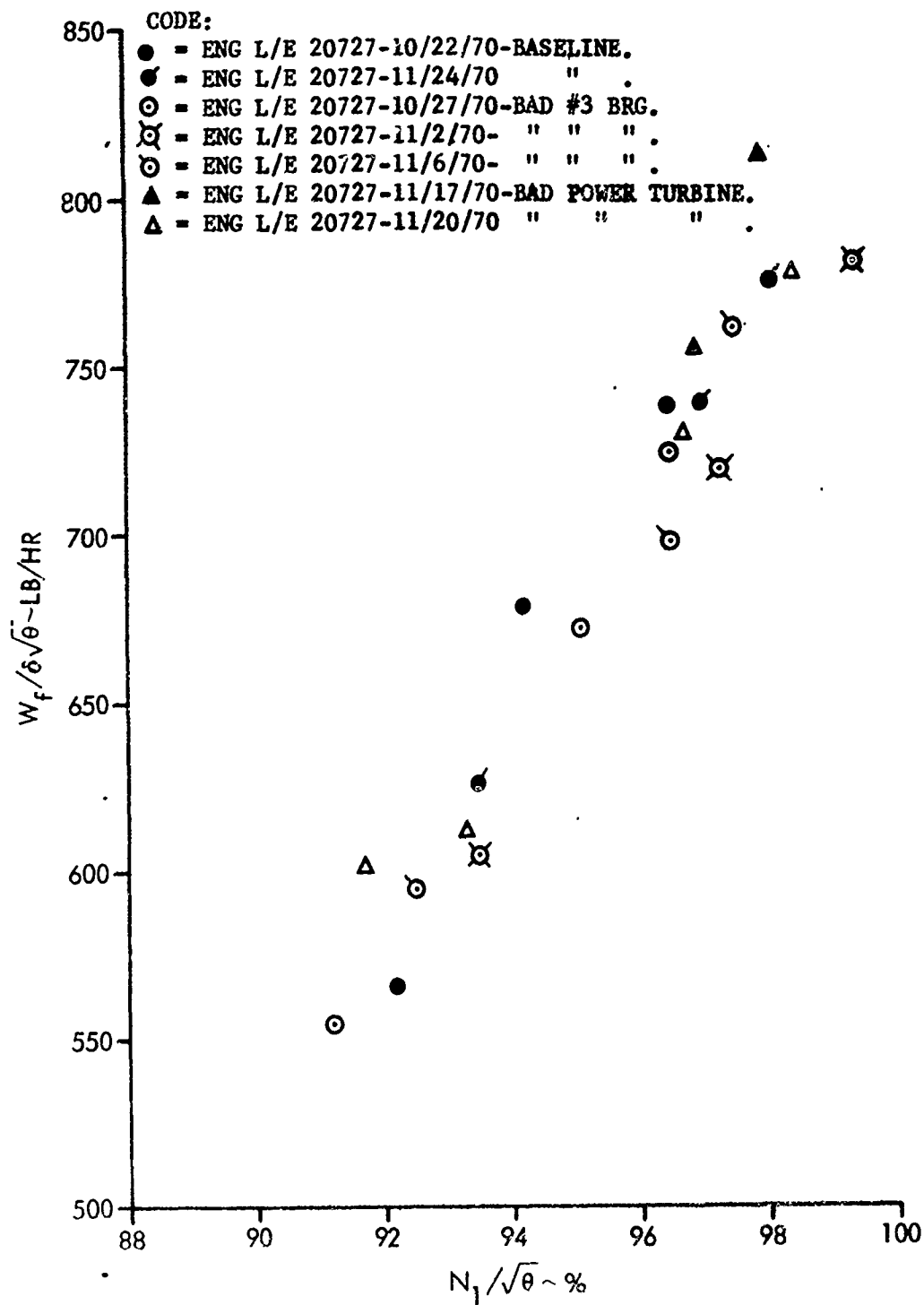


FIGURE 5-42 CORRECTED FUEL FLOW VS CORRECTED  $N_1$  SPEED

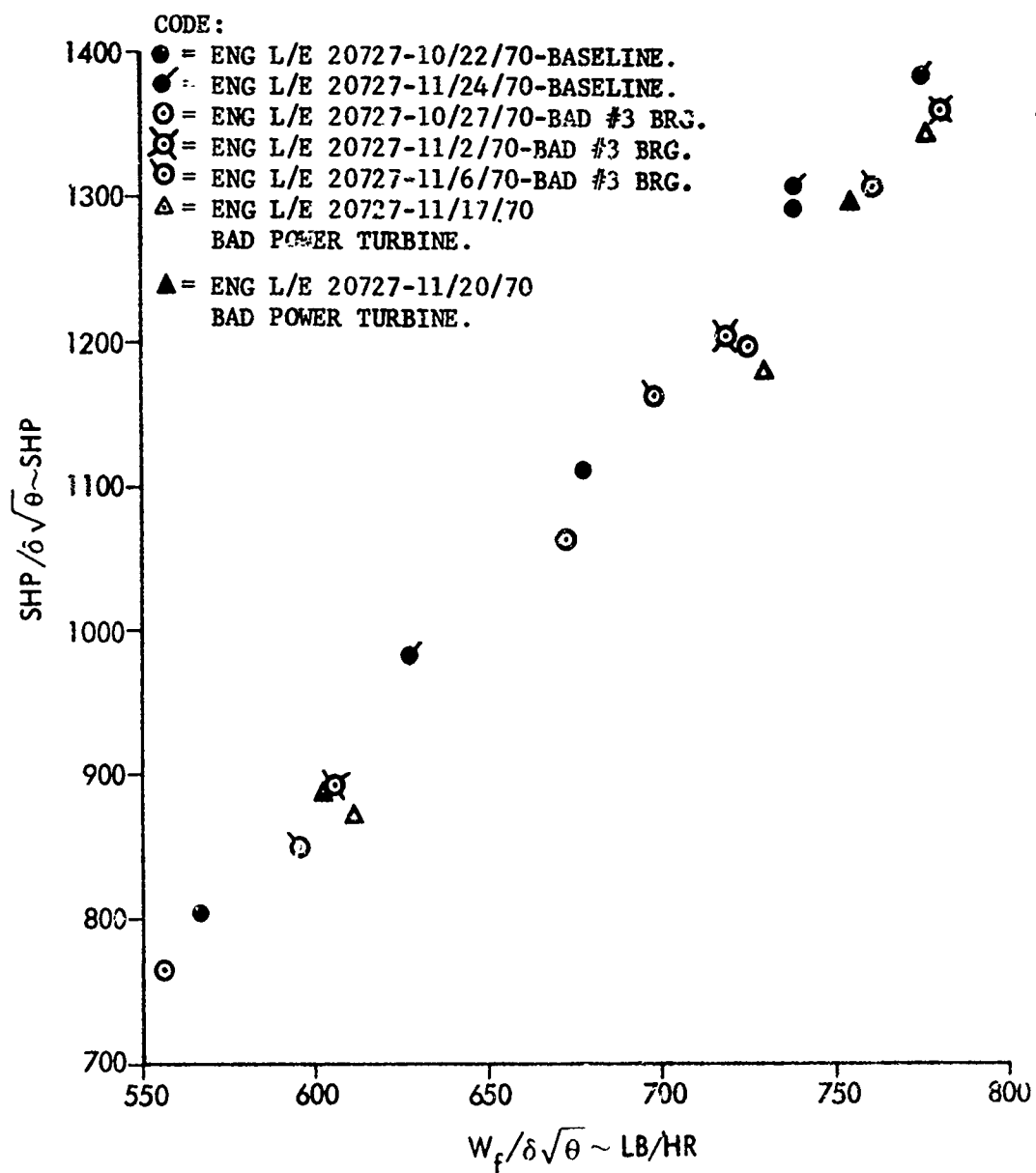


FIGURE 43 CORRECTED SHAFT HORSEPOWER VS CORRECTED FUEL FLOW

Direct comparison of the baseline and discrepant engine performance show the following.

- a) Selected discrepant number 3 bearings were not damaged enough to affect the engine performance. Only noticeable performance changes from the baseline values were indicated on the second degraded number 3 bearing engine run (2 November 1970). Lower shaft horsepower and EGT achieved on this test may have been caused by an engine adjustment which modified the engine fuel flow schedule.
- b) Of the two defective power turbine engine runs, the second engine test (20 November 1970) provided the typical problems encountered on the defective power turbine engine. Apparent performance indicators are the engine shaft horsepower deficiency and irregular exhaust gas temperatures as a function of engine speed (figures 5-40 and 5-41), no effect on compressor performance (Figure 5-39), and reduced shaft horsepower per engine fuel flow (Figure 5-43).

Table 5.7 has been prepared to completely summarize the results of the engine analysis performed during the test cell phase.

#### 5.7.4 ENGINE BEARING TEMPERATURE

Figures 5-44, 5-45, and 5-46 illustrate the engine number 2 bearing and number 3 and number 4 bearing scavenge oil temperature rise over the engine oil input temperature. Standard test cell instrumentation was used to obtain this data. It was verified that test cell readings were lower than Northrop readings due to the physical differences in the sensor installations. However, test cell temperatures were chosen for evaluation since they provide a broader data base for comparison.

Correlation between discrepant bearings and temperature rise was not fully conclusive. The primary observation is that distinct data shifts result from engine teardown. This shift was observed in the number 2 bearing differential temperature on engine 18993, which had the same number 2 bearing installed in all test cell runs. In the case of engine 20727 on 2 November 1971, a distinct temperature rise was observed when a discrepant number 3 bearing was implanted. However, in subsequent tests the number 3 and number 4 bearing differential temperature remained at essentially the same levels in spite of the restoration of the original bearing.

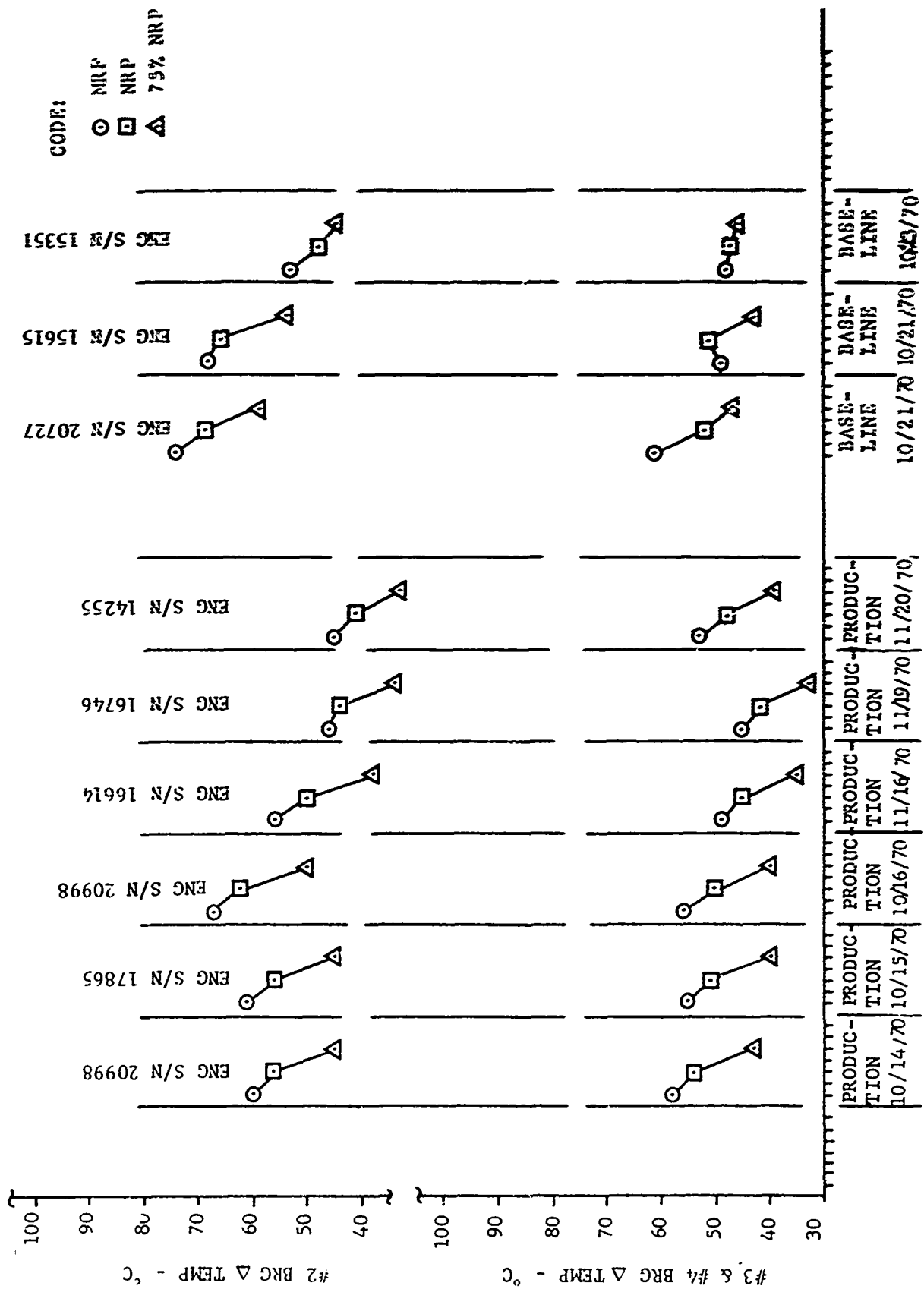


FIGURE 5-44 BEARING DIFFERENTIAL TEMPERATURE FOR TEST CELL OVERHAUL ENGINES

ENC S/N 15615

ENC S/N 18993

CODE 1  
 ○ = MAP  
 □ = MAP  
 ▲ = 75% MAP

#2 BRG TEMP. - °C

#3 & 4 BRG TEMP. - °C

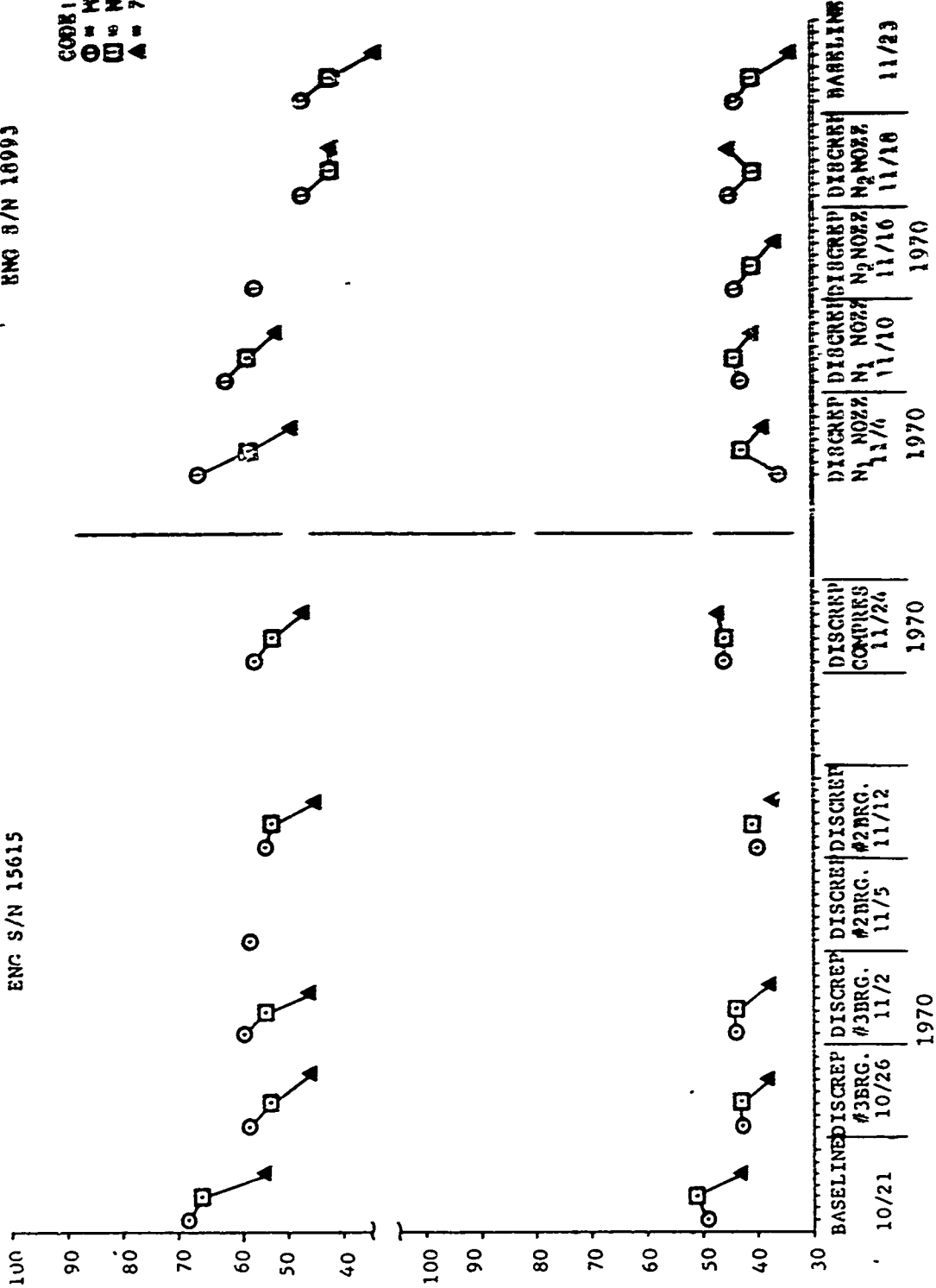


FIGURE 5-45 BEARING DIFFERENTIAL TEMPERATURE FOR 'TNS' CELL BASELINE AND DISCREPANT TESTS

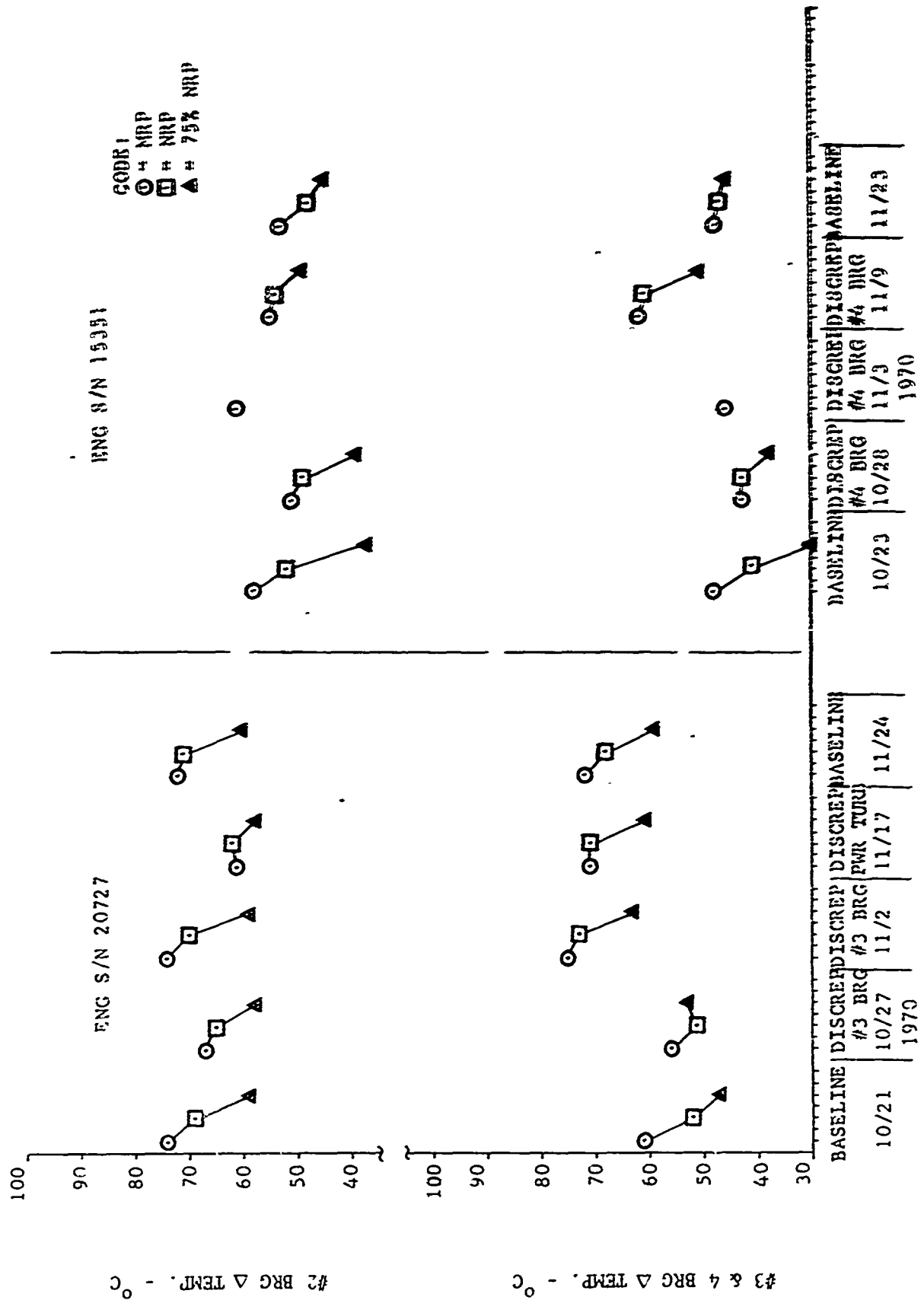


FIGURE 5-46 BEARING DIFFERENTIAL TEMPERATURE FOR TEST CELL BABLINE AND DISCREPANT TH3418

TABLE 5.7 SUMMARY OF DISCREPANCY

ENGINE S/N	DATE OF TEST	DISCREPANT PART	CPR vs $N_1/\sqrt{\theta}$
20727	10-27-70	No. 3 Bearing	Slightly Lower (<2%) & Slightly Higher (<2%)
	11-2-70	No. 3 Bearing	Slightly Lower (<2%)
	11-6-70	No. 3 Bearing	Slightly Lower (<2%) & Slightly Higher (<2%)
	11-17-70	Power Turbine	Higher (>2%, <10%)
	11-20-70	Power Turbine	Slightly Lower (<2%) & Slightly Higher (<2%)
18993	11-4-70	$N_1$ Nozzles	Slightly Lower (<2%)
	11-10-70	$N_1$ Nozzles	No Effect
	11-16-70	$N_2$ Nozzles	Slightly Higher (<2%)
	11-18-70	$N_2$ Nozzles	Slightly Higher (<2%)
15615	10-26-70	No. 2 Bearing	Much Lower (<10%)
	10-30-70	No. 2 Bearing	Lower (>2%, <10%)
	11-5-70	No. 2 Bearing	Lower (>2%, <10%)
	11-12-70	No. 2 Bearing	No Effect
	11-19-70	Compressor	Lower (>2%, <10%)
	11-24-70	Compressor	Slightly Lower (<2%)
15351	10-28-70	No. 4 Bearing	Lower (>2%, <10%)
	11-3-70	No. 4 Bearing	Lower (>2%, <10%)
	11-9-70	No. 4 Bearing	Slightly Lower (<2%)

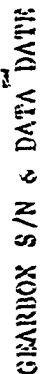
$E_{GT}/\theta$ vs $E_1/\sqrt{\theta}$	$W_F/\sqrt{\theta}$ vs $E_1/\sqrt{\theta}$	$SE/\sqrt{\theta}$ vs $E_1/\sqrt{\theta}$	$SE/\sqrt{\theta}$ vs $W_F/\sqrt{\theta}$
Lower (>2%, <10%)	No Effect	Slightly Lower (<2%)	Lower (>2%, <10%)
Slightly Higher (<2%)	Lower (>2%, <10%)	Lower (>2%, <10%)	Slightly Lower (<2%)
Slightly Lower (<2%)	No Effect	Slightly Lower (<2%)	Slightly Lower (<2%)
Slightly Higher (<2%)	Slightly Higher (<2%)	No Effect	Lower (>2%, <10%)
Slightly Higher (<2%)	Slightly Lower (<2%) & Higher (>2%, <10%)	Lower (>2%, <10%)	Lower (>2%, <10%)
Lower (>2%, <10%)	Lower (>2%, <10%)	Lower (>2%, <10%)	Slightly Lower (<2%)
Lower (>2%, <10%)	No Effect	Lower (>2%, <10%)	Lower (>2%, <10%)
Much Lower (<10%)	No Effect	Slightly Lower (<2%)	Slightly Lower (<2%)
Slightly Higher (<2%)	No Effect	Lower (>2%, <10%)	Lower (>2%, <10%)
Lower (>2%, <10%)	Much Lower (<10%)	Much Lower (<10%)	Lower (>2%, <10%)
Lower (>2%, <10%)	Much Lower (<10%)	Much Lower (<10%)	Slightly Lower (<2%)
Slightly Lower (<2%)	Lower (>2%, <10%)	Much Lower (<10%)	Slightly Lower (<2%)
Lower (>2%, <10%)	Lower (>2%, <10%)	Much Lower (<10%)	Slightly Lower (<2%)
Lower (>2%, <10%)	Much Lower (<10%)	Much Lower (<10%)	Lower (>2%, <10%)
Lower (>2%, <10%)	Much Lower (<10%)	Much Lower (<10%)	Slightly Higher (<2%)
Higher (>2%, <10%)	Slightly Lower (<2%)	No Effect	No Effect
No Effect	Much Lower (<10%)	Lower (>2%, <10%)	No Effect
Higher (>2%, <10%)	Slightly Lower (<2%)	Slightly Lower (<2%) & Slightly Higher (<2%)	No Effect

### 5.7.5 GEARBOX TEMPERATURES

Figure 5-47 illustrates the 42-degree gearbox differential temperature rise for baseline, discrepant, and high time units. Figure 5-48 contains the same information for the 90-degree gearbox. Overall, the results show some correlation of discrepant parts with respect to baseline data. Of the 62 discrepant conditions imposed, 24 of them exhibit a temperature rise above the baseline spread. High time units consistently exhibit a lower temperature rise after they have been overhauled, and in addition, definitely trend toward the low end of the baseline temperature range. None of the high time units exceeded the temperature range established by the baseline units. In fact, a few were quite low, notably 42-degree gearbox B13-854. This implies that some of the high time units have useful service life remaining.

### 5.8 CONCLUSIONS

Both objectives of the test cell phase were met. First, a data base was developed of serviceable and degraded component performance and parameter variations in the test cell environment. Secondly, the successful integration and operation of the MRS system with the UH-1H test bed aircraft was assured.



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## **SECTION 6**

## 6.0 PREPARATION FOR FLIGHT TEST PHASE

### 6.1 OBJECTIVE

The objective was to instrument two UH-1H helicopters for flight test of the Maintenance Reporting System (MRS). One helicopter was used for installation of LRU's which had implanted discrepant parts. The other was used as a "trend" aircraft which flew typical Army missions and accumulated as many flight hours as practical during the program.

### 6.2 SYSTEM INSTALLATION

Installation in the two helicopters was essentially identical except that the trend aircraft 66-17138 did not have provisions for using the Leach instrumentation recorder (provisions were added at the start of verification testing). Certain accelerometers were also not installed in 66-17138 because they were intended for analysis support data and were not used by MRS mechanization. These accelerometers (five) are listed in Table 6.1.

Figure 6-1 illustrates the location where new sensors were added to the helicopter. Reference numbers are explained in Table 6.1. The majority of the sensor mounting brackets came from the test cell instrumentation. Others which were peculiar to this installation, or were determined to be required for the flight phase, were manufactured in the ARADMAC machine shop. In addition, hardware required for new pressure lines was obtained from the ARADMAC standard parts inventory. Added pressure tubing on engine, transmission and hydraulic systems were made from stainless steel, braided, flexible tubing with a service rating of at least 2-1/3 times the maximum system pressure. Pressure sensing lines were provided with a 0.040-inch-diameter flow restrictor at the tie-in point to critical aircraft subsystems.

Figure 6-2 illustrates the UH-1H instrumentation cable routing. A large portion of the wiring was manufactured into cable assemblies prior to the installation. This procedure reduced the time and effort expended.

In the selection of signal sources, indicator circuits were utilized to assure greater flight safety. However, whenever critical control circuits had to be monitored, an encapsulated protective resistor or a suitable fuse

at the interface junction was used to protect the aircraft circuit from a possible short circuit in the MRS wiring.

Figures 6-3, 6-4, 6-5, and 6-6 show typical sensor installations in the transmission, engine, and gearbox areas. Reference numbers are explained in Table 6.1.

### 6.3 PREFLIGHT CHECKOUT

After the aircraft installation was completed, a system checkout was initiated. First, the instrumentation wiring was verified for accuracy against the schematics. Next, the transfer function from the sensor through the signal conditioning was established. This procedure involved sensor simulation, as in the case of the temperature probes, or direct physical sensor excitation, as in the case of the pressure transducers and EGT probes. The final phase of the preflight checkout included engine ground runs which verified the mechanical integrity of the helicopter rework.

TABLE 6.1 ADDED SENSORS

NUMBER	FUNCTION MEASURED	SENSOR
1	Interstage Airbleed Closure	6HM1-1 Micro-Switch (M.H.)
2	Compressor Discharge Pressure	PA 208TC-100 Statham Press. Transducer
3	Ambient Pressure	PA 208TC-15 Statham Press. Transducer
4	Inlet Guide Vane Position	CIC #78 Potentiometer
5	Fuel Flow	1/2-2-81-200 Foxboro Flowmeter
6	Vibration - Engine Compressor	6222M2 Endevco Accelerometer
7	Vibration - Engine Combustor	6222M2 Endevco Accelerometer
8	Vibration - Engine Turbine	6222M2 Endevco Accelerometer
9	Fuel Pressure	PG132TC-50 Statham Press. Transducer
10	Eng. Oil Filter Condition - Clogging	41D23 Custom Component Press. Switch
11	Eng. Oil Cooler Operation - Inlet Temp.	MS28034-3 Temp. Bulb
12	Eng. Oil Cooler Operation - Exit Temp.	MS28034-3 Temp. Bulb
13	#2 Bearing Scavenge Oil Temp.	MS28034-3 Temp. Bulb
14	#3, 4 Bearings Scavenge Oil Temp.	MS28034-3 Temp. Bulb
15	Accessory Drive Gear Box Pressure	PG 132 TC-5 Statham Press Transducer
16	Transmission External Filter Condition - Clogging	42D254 Custom Component Press. Switch
17	Transmission Internal Filter Condition - Clogging	42D254-1 Custom Component Press. Switch
18	Transmission Oil Cooler Operation - Inlet Temp.	MS28034-3 Temp. Bulb
19	Transmission Oil Cooler Operation - Exit Temp.	MS28034-3 Temp. Bulb
20	Vibration - Transmission - Lateral Cover Plate	6222M3 Endevco Accelerometer
21	Vibration - Transmission - Normal Mast	6222M3 Endevco Accelerometer
22	Vibration - Transmission - Normal Input	6222M3 Endevco Accelerometer
23	Vibration - Transmission - Longitudinal Input	6222M3 Endevco Accelerometer
24	Vibration - Transmission - Lateral TR Output	6222M3 Endevco Accelerometer
25	Vibration - Transmission - Longitudinal TR Output	6222M3 Endevco Accelerometer
26	Vibration - 90° Gear Box - Lateral	6222M3 Endevco Accelerometer
27	Vibration - 90° Gear Box - Normal	6222M3 Endevco Accelerometer
28	Vibration - 42° Gear Box - Normal	6222M3 Endevco Accelerometer
29	Vibration - 42° Gear Box - Longitudinal	6222M3 Endevco Accelerometer
30	42° Gear Box External Temp.	118G Rosemount Surface Gage
31	42° Gear Box Internal Temp.	118G Rosemount Surface Gage
32	90° Gear Box External Temp.	118G Rosemount Surface Gage
33	90° Gear Box Internal Temp.	118G Rosemount Surface Gage
34	Hydraulic Overpressure	98G191 Custom Component Press. Switch
35	Hydraulic Fluid Temperature	56B32B Lewis (High Press.) Temp. Bulb
36	Pilot's Normal Acceleration	Statham AJ-43 Accelerometer
37	Pilot's Lateral Acceleration	Statham AJ-43 Accelerometer
38	Ambient Air Temperature	54B Lewis Temp. Probe

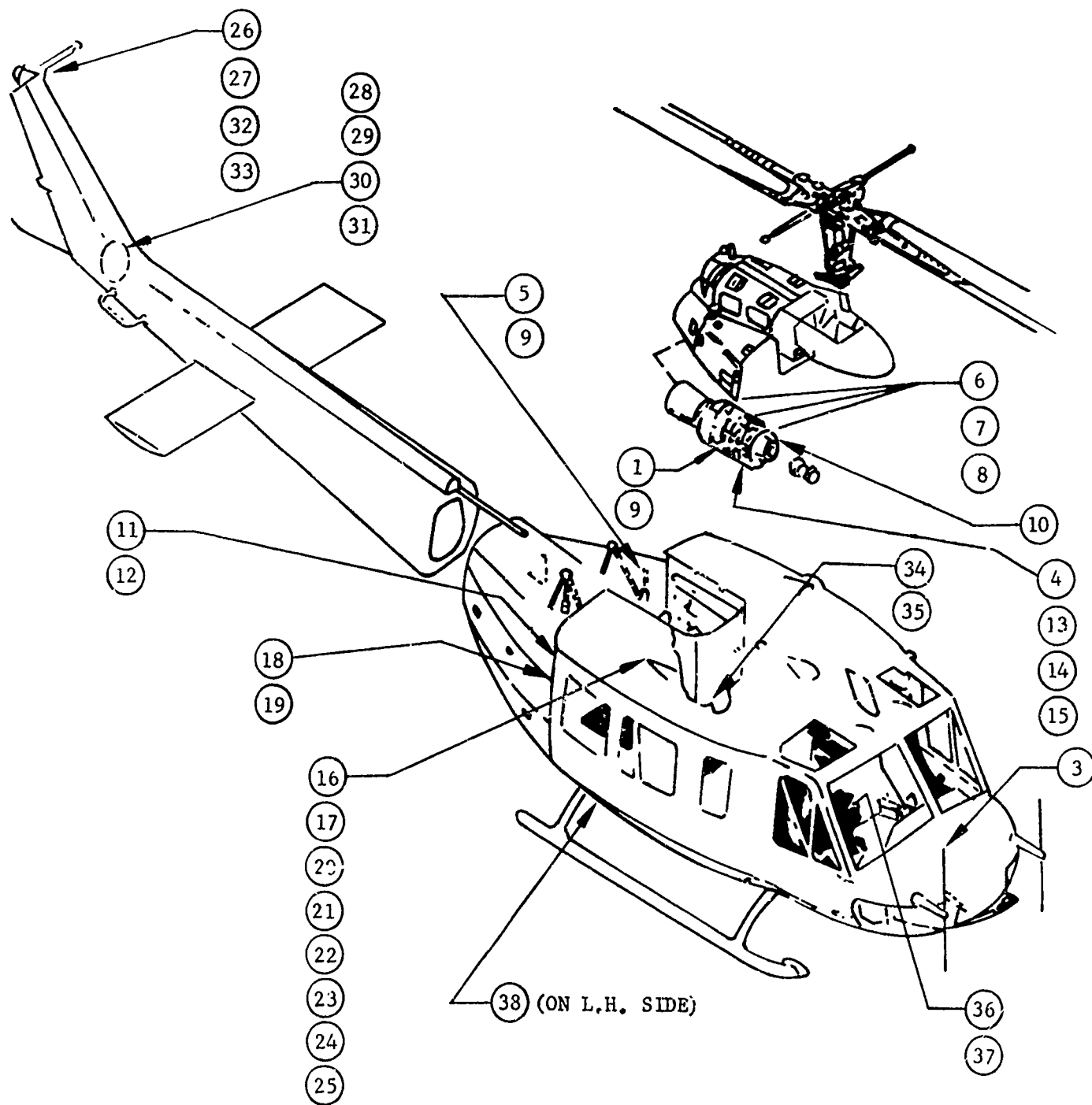
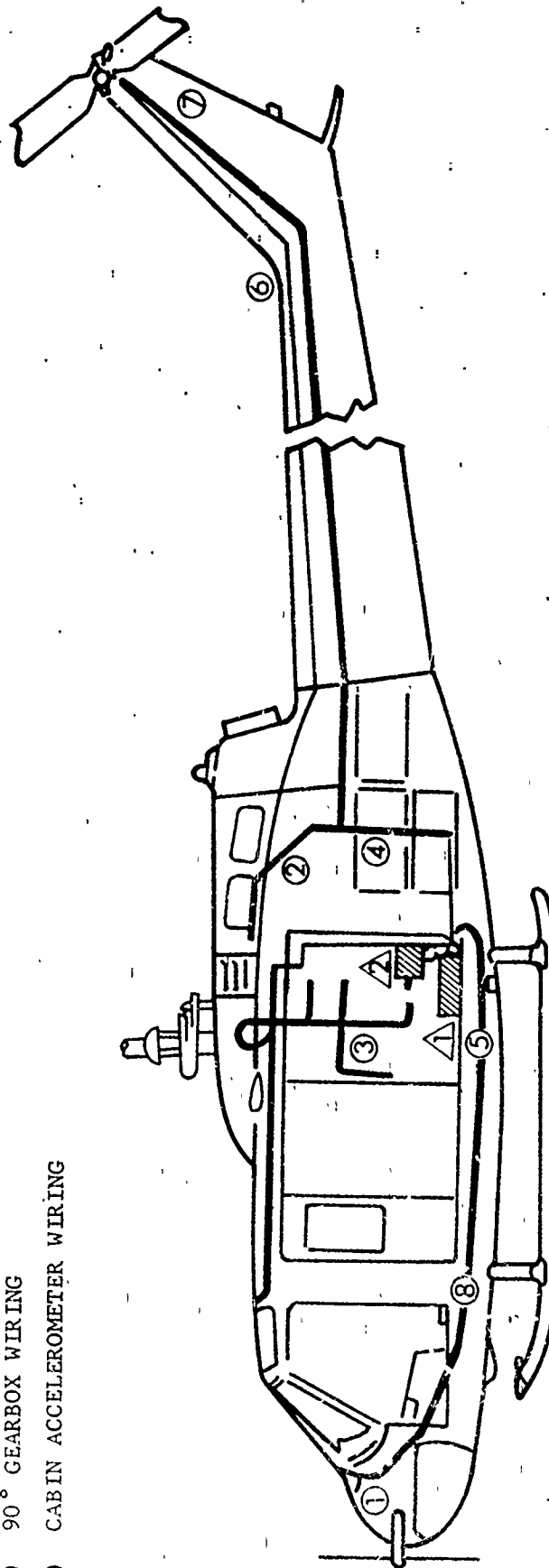


FIGURE 6-1 LOCATION OF ADDED MRS SENSORS

- ① NOSE AREA WIRING
- ② ENGINE AREA WIRING
- ③ PYLON AREA WIRING
- ④ CENTER FUSELAGE WIRING
- ⑤ OAT WIRING
- ⑥ 42° GEARBOX WIRING
- ⑦ 90° GEARBOX WIRING
- ⑧ CABIN ACCELEROMETER WIRING



△ MRS ELECTRONIC UNIT  
 △ CIPR RECORDER

FIGURE 6-2 UH-1H INSTRUMENTATION CABLE ROUTING

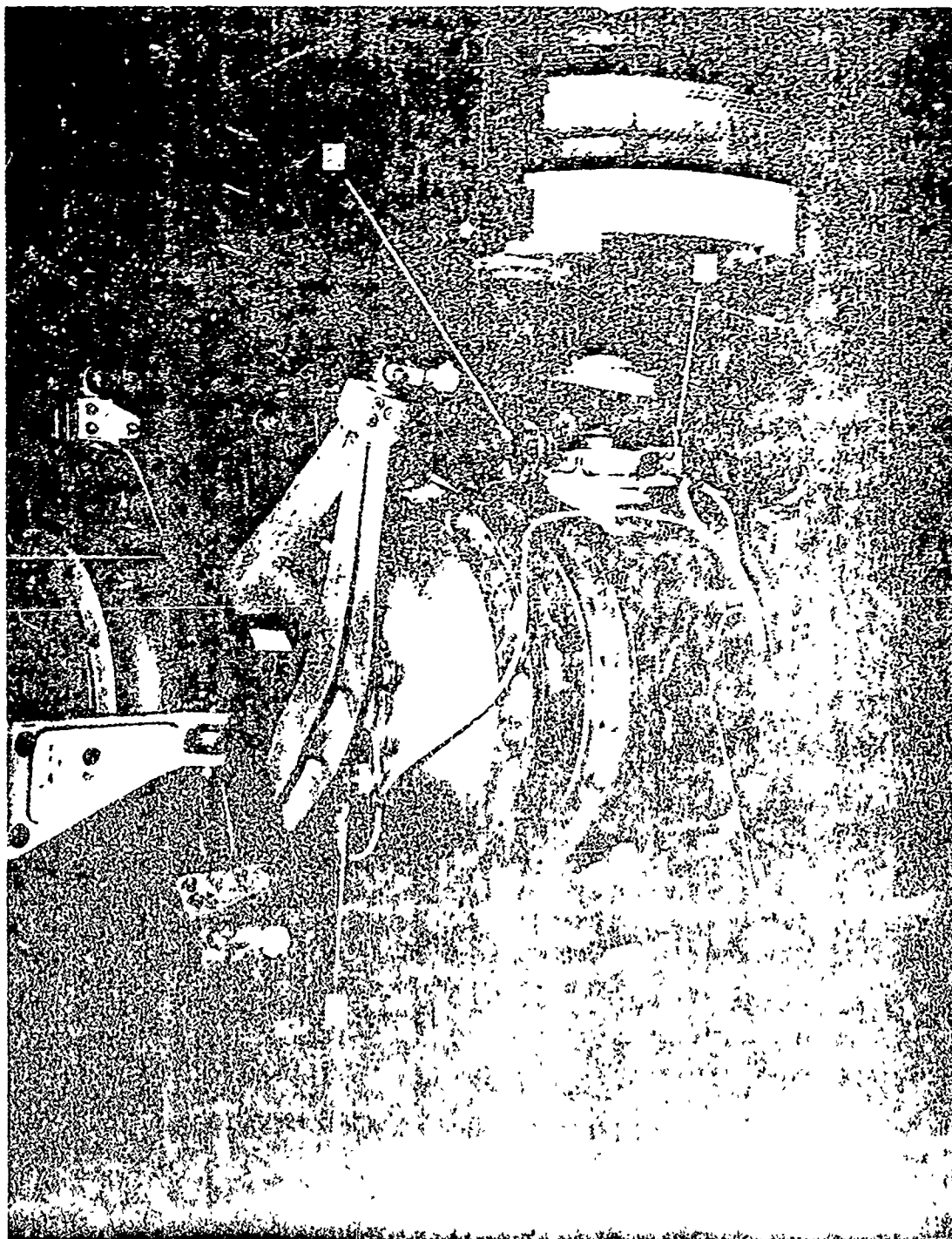


FIGURE 6-3 TRANSMISSION INSTALLATION

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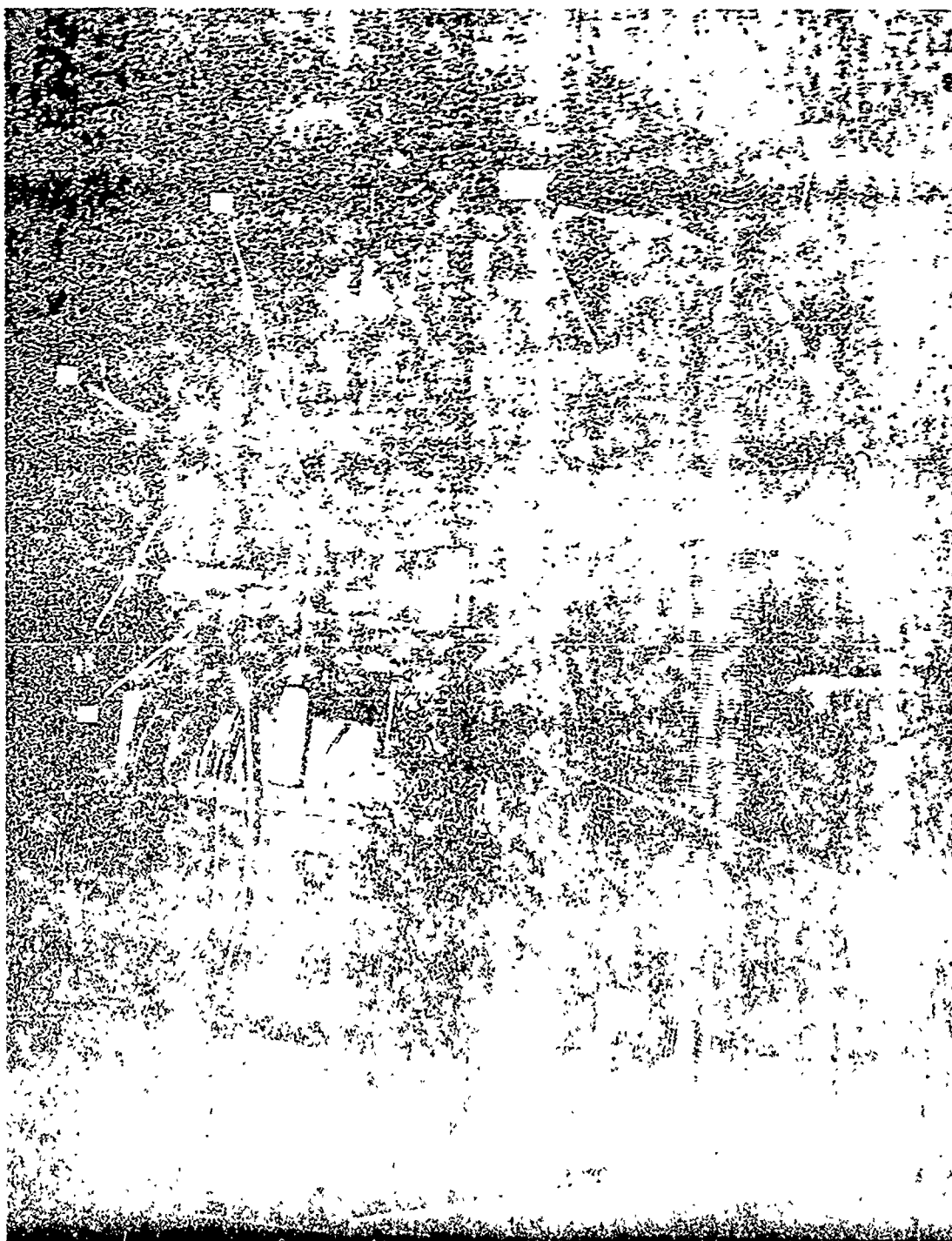


FIGURE 6-6 ENGINE INSTALLATION

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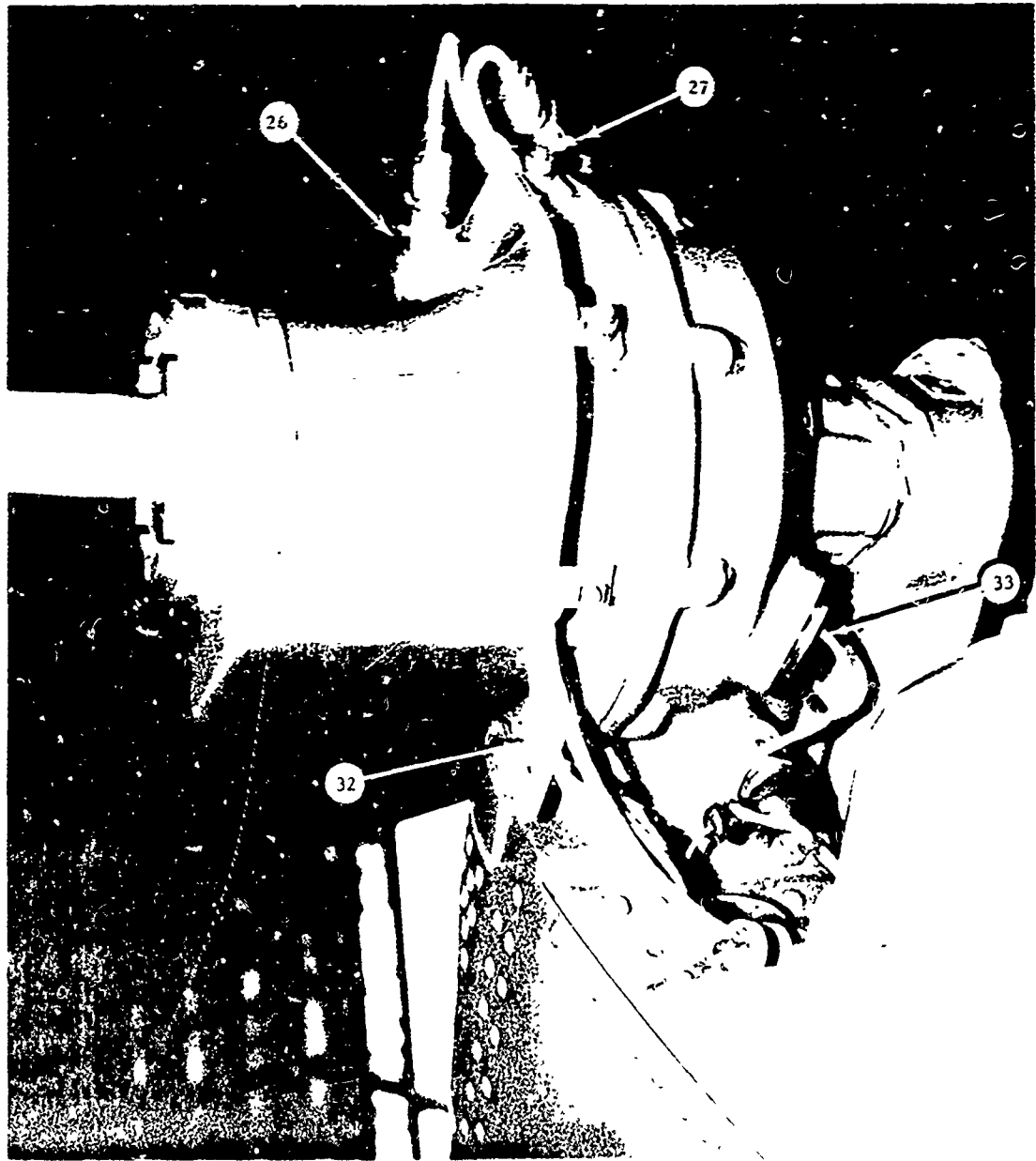


FIGURE 6-5 90° GEARBOX

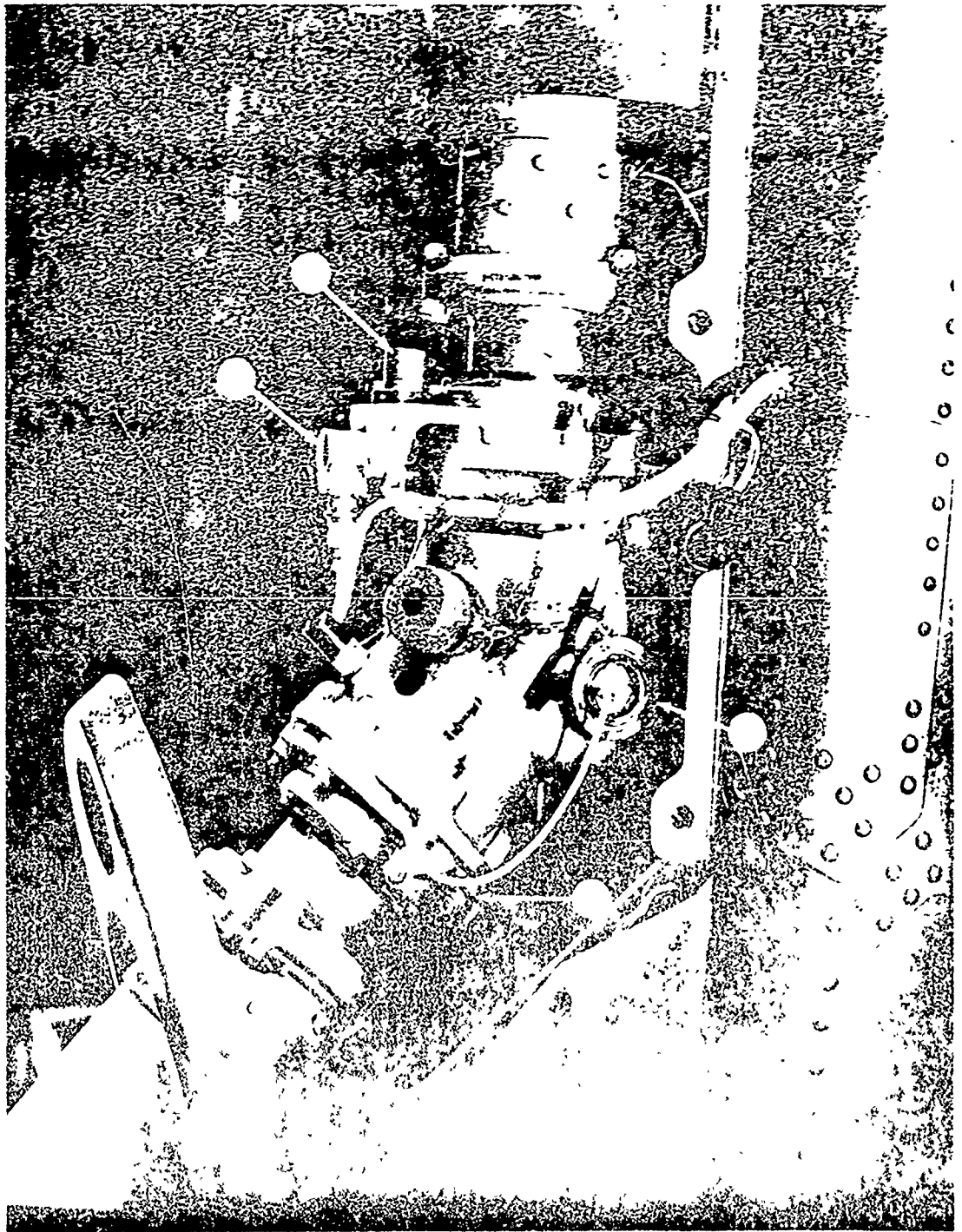


FIGURE 5-6 42" GEARBOX

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## **SECTION 7**

## 7.0 FLIGHT TEST PHASE

This portion of the test bed program incorporated all the planning and "lessons learned" from previous phases, with emphasis on correlation of the data from the test cell operation. The flight program was implemented in two helicopters assigned to Northrop. Both aircraft were continuously flown at maximum gross weight; a standard flight profile which parallels Army test flight requirements was utilized; Army mechanics accomplished the bulk of the aircraft maintenance functions; and Army Aviators with extensive, recent combat operational and logistical experience did all the flying. As detailed in Paragraph 7.2, the flight phase scope included baseline, discrepant parts implant, trending and verification flights.

### 7.1 OBJECTIVES

The objectives of the flight test phase were to:

- a) Provide signature data for MRS parameters under varying flight conditions.
- b) Verify UH-1H/MRS compatibility under operational conditions.
- c) Demonstrate MRS performance throughout the normal range of UH-1H aircraft operations.
- d) Accumulate the data necessary for the Army to project the logistical impact provided by the MRS on the aviation fleet.

### 7.2 TEST CONDUCT

The flight test phase used two UH-1H aircraft with T53-L-13 engines for data acquisition. Aircraft 67-17448 was used primarily for discrepant parts and baseline flights; aircraft 66-17138 was used primarily for obtaining trend data while accumulating as many hours as possible. Except during the incidents and verification flight tests, the trend aircraft flew a wide range of Army aviation missions. During the program, aircraft 66-17138 logged 236 hours, while aircraft 67-17448 accumulated 86 hours.

### 7.2.1 TEST SAMPLES

Parts used for discrepant implants were primarily taken from the original group selected for the test bed program and included many parts used in the test cell. The bulk of the parts were chosen by qualitative assessment based upon the experience of ARADMAC personnel in the overhaul and manufacture of engines, transmissions, and gear boxes. Parts used as discrepant implants are listed in table 7.1.

### 7.2.2 PROCEDURE FOR DISCREPANTS

The sequence of installation and removal of discrepant parts is shown in the Engine and Transmission Box Test Cycle diagram of figure 7-1. Essentially, the same sequence was used during discrepant baseline tests. Engines, transmissions, 42° gear boxes, and 90° gear boxes were built-up by ARADMAC personnel with the selected parts implanted during build-up. Army crew chiefs assigned to the program installed the discrepant components on the test aircraft.

NED personnel were responsible for removing and installing the new test bed sensors which were affected by the removal and installation of each discrepant component. Integrity of installations was confirmed by a ground run-up of the aircraft with the complete MRS operating (including the Leach instrumentation recorder).

Inasmuch as flight time for each discrepant was limited to 2-1/2 hours, every effort was made to assure successful data acquisition. The NED discrepant flight profile required approximately 50 minutes per flight, which allowed 2 flights per discrepant. At the end of the first flight, data was checked and verified before the second flight was allowed to start. The second flight was primarily a back-up, but did provide special data on some flights, particularly after the vibration spectrum analyzer (VSA) method of monitoring was incorporated in the MRS (reference Section 3.3.1).

At the completion of the second flight, data was again checked before the discrepant components were allowed to be removed from the aircraft.

TABLE 7.1 DISCREPANT PARTS COUNT FLIGHT PROGRAM

	BASELINE	INPUT BRG	OUTPUT BRG	MAST BRG	#2, #3, #4 BEARINGS	COMPRESSOR	TURBINE	NOZZLES	TOTAL
ENGINES	5				6	2	2	4	19
TRANSMISSIONS	5	2	* 2	2					11
90° GEAR BOXES	5	4	4						13
42° GEAR BOXES	5	4							9

\*TAIL ROTOR

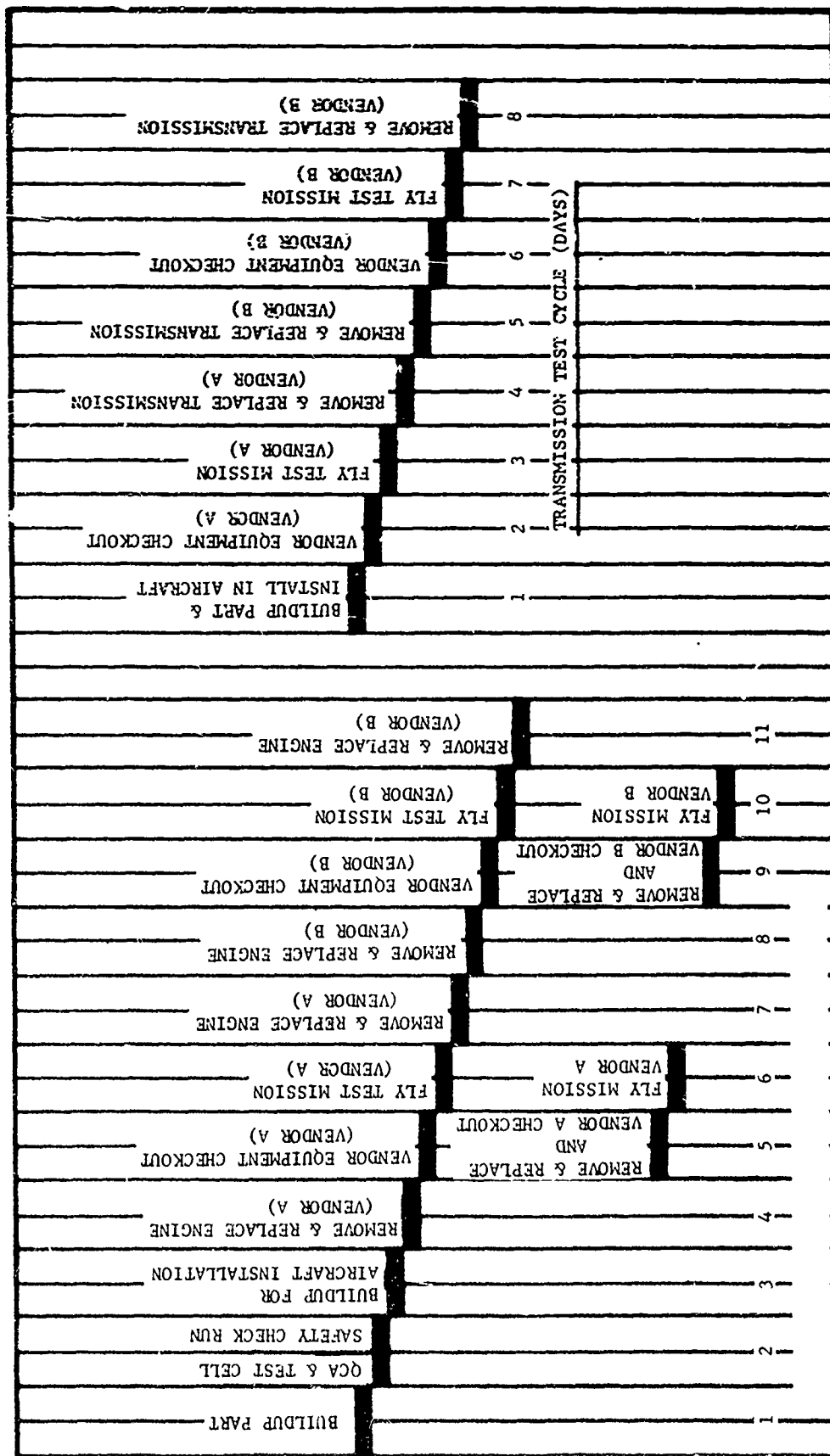


FIGURE 7-1 ENGINE AND TRANSMISSION TEST CYCLE (DAYS)

### 7.2.3 DATA REDUCTION

Reducing the data acquired from the test aircraft was accomplished at both Corpus Christi and at Northrop's Palos Verdes facility (the Corpus Christi activity was accomplished in a house trailer adjacent to ARADMAC).

At Corpus Christi, the CIPR cartridge was removed from the aircraft after a flight and the data accumulated was recovered by using the Data Recovery Unit (DRU) to play back the magnetically stored data. Both the maintenance and engineering channels were printed out and used to evaluate system performance and to verify the occurrences of maintenance outputs. Copies of both maintenance and engineering channel data of each flight were sent to Palos Verdes for detailed evaluation.

Reduction of data at Palos Verdes was concerned with supplying data for three primary types of evaluation efforts. Reels of magnetic tape containing broadband vibration data, recorded by the Leach airborne recorder, were received from Corpus Christi and played back on an Ampex instrumentation playback machine and an SD301B real time analyzer. This analyzer was set up to record power spectrum density (PSD) outputs directly on an X-Y plotter. The PSD plots were used for detailed evaluation of acceleration information sensed at various points on aircraft components.

Copies of the engineering channel data for each flight received from Corpus Christi were transcribed for use in a computer program which converted pertinent data to a form suitable for evaluation of engine gas dynamics. Data from the computer program was organized into various forms for comparing health and trend relationships, examples of which are contained in this report.

Other data from the engineering channel and maintenance channel was compiled and plotted for observing changes from established baseline conditions and for evaluating system mechanization.

### 7.3 SHAKEDOWN FLIGHTS

Prior to the start of actual flight tests, several flights were made to assure operation of the complete system. Verifying that the installation was

correct and flightworthy was the primary purpose. In conjunction with these installation integrity checks, evaluation of data proved the outputting capability of the system during various flight conditions. A correlation of MRS calibration to cockpit instrumentation was also obtained for a better understanding of flight data.

Of lesser importance but significant to the conduct of flight tests was the information gained from the shakedown flights which aided in establishing procedures for conducting flights and handling data in support of flights.

#### 7.4 INCIDENT FLIGHTS

Incident flights were devised to demonstrate the performance of the MRS by establishing conditions which would cause the system to output correctly without creating hazardous conditions. With the MRS hardware installed for normal monitoring, a special test box was connected to the EU test connector during the incident flights. This special test box was capable of substituting a different detection level (value determined by operator) for any of the pre-established detection levels contained in the EU mechanization. Detection levels in the upper ends of the "normal" range of selected parameters were substituted for abnormal limits by programming the special test box and then varying the flight conditions of the aircraft to obtain the desired upper range conditions.

On 3 flights of aircraft 67-17448, the following conditions were demonstrated by substituting detection levels:

<u>Condition</u>	<u>Normal Limit</u>	<u>Demonstration Limit</u>
Overtorque	50 psi	48 psi
N1 Overspeed	101.5%	98%
N2 Overspeed	6640 RPM (N1 91%)	6400 RPM
Rotor Overspeed	339 RPM	320 RPM
Engine Oil Overtemp	93°C	85°C
EGT Abnormal	625°C	600°C

Engine oil overtemperature and EGT abnormal were not accomplished on all flights because of the inability to create the upper limit condition each time.

In addition to the detection level substitution tests, several aircraft switch type parameters were tested.

### 7.5 ROTOR FLIGHTS

Several flights were made to obtain vibration reference data during known out-of-tolerance conditions of main and tail rotors. This data, recorded by the Leach instrumentation recorder, was to be used for evaluation of detection mechanizations.

Spanwise and chordwise unbalance as well as low speed and high speed out-of-track tests were devised and used for main rotor tests. Out-of-track and out-of-balance tests were also used for the tail rotor. All tests, except tail rotor unbalance, were flown only once because of poor flying weather, and due to AVSCOM's desire to begin other tests.

After a baseline (in tolerance) data flight, the following test conditions were created using aircraft 17448:

<u>Condition</u>	<u>Method Used</u>
Main rotor spanwise unbalance	5 wrap weight added
Main rotor chordwise unbalance	Shorten drag link 1 turn
Main rotor low speed out-of-track	Lengthen drag link
Main rotor high speed out-of-track	Adjust trim tabs
Tail rotor out-of-balance	2 wraps 2 inch tape
Tail rotor out-of-track	Adjust pitch link

No significant correlation of abnormal conditions was observed from the limited amount of data obtained. Further testing with a more flexible instrumentation scheme, which can be adjusted to accumulated results, would be of value in determining monitoring requirements for rotor type problems.

### 7.6 BASELINE FLIGHTS

The purpose of baseline flights was to accumulate data which would provide the data base necessary for diagnostic analysis of discrepant implants. Establishing the necessary data base required data to be acquired from "no defect" flights of each S/N component used for implants (see table 7.2) as well as data

TABLE 7.2 BASELINE (NO DEFECT) FLIGHTS

<u>DATE</u>	<u>COMPONENTS</u>
5-3-71	Engine S/N 20727 42° Gear Box S/N ABB-289 90° Gear Box S/N A13-2772 Transmission  Mast Bearing S/N 833E Input Quill Bearing S/N Q12-520 Tail Rotor Quill Bearing S/N F12-6215
5-12-71	Engine S/N 15615 42° Gear Box S/N B13-2925 90° Gear Box S/N A13-2065 Transmission  Mast Bearing S/N 198K Input Quill Bearing S/N G12-1341 Tail Rotor Quill Bearing S/N F12-6277
5-17-71	Engine S/N 18993 42° Gear Box S/N B13-8304 90° Gear Box ABC-142 Transmission  Mast Bearing S/N 67 Input Quill Bearing S/N CP12-4268 Tail Rotor Quill Bearing S/N B12-55524
5-24-71	Engine S/N 15351 42° Gear Box S/N B13-5199 90° Gear Box S/N B13-6624 Transmission  Mast Bearing S/N 612J Input Quill Bearing S/N CP12-7105 Tail Rotor Quill Bearing S/N B12-18628

from flights with different gross weights using the normal service components of aircraft 67-17448 during January 1971.

#### 7.6.1 BASELINE FLIGHT PROFILE

A flight profile which would provide a flexible basis for evaluating data was used for baseline flights (see figure 7-2). This profile was also used for all discrepant parts flights except that the maximum altitude of 10,000 feet used on early baseline flights was changed to 4,000 feet to better accommodate the flying conditions at Corpus Christi (usually IFR above 4,000' MSL).

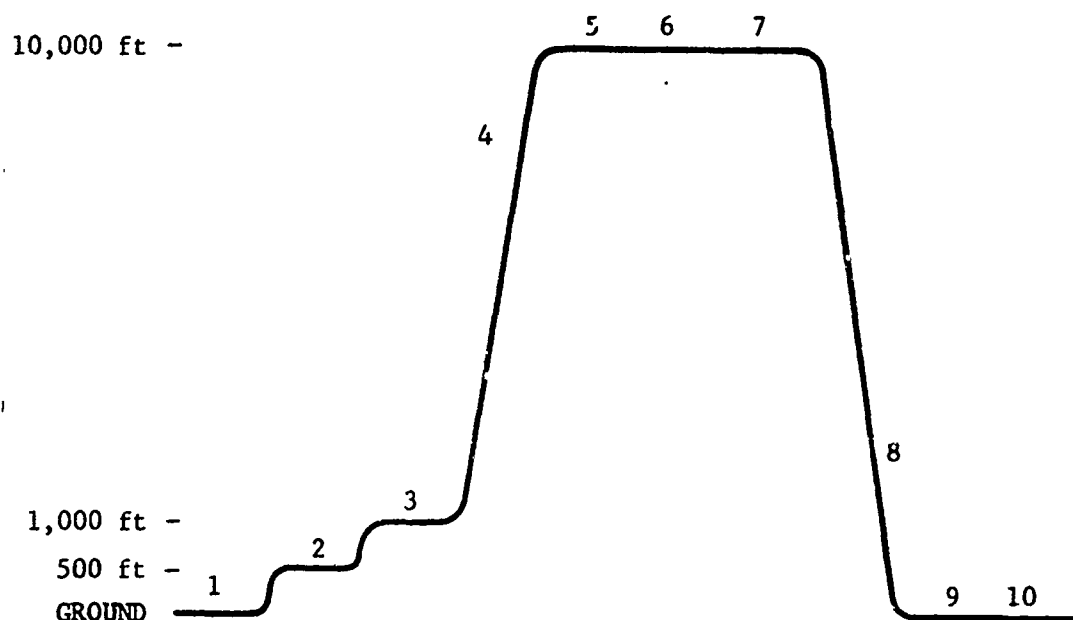
Data was recorded on the CIPR and on the Leach instrumentation recorder for each step of the profile. Accumulation of the data obtained from these steps covered a variety of power and trim conditions which allowed comparison of data within a flight as well as comparison of flight to flight.

#### 7.6.2 BASELINE EVALUATION

Since baseline data is presented and used in other sections of this report, discussion here is limited to factors which influence primarily the interpretation of the baseline data.

The first baseline flights were flown in January with different "onboard" weights and used the normal service engines assigned to each aircraft. Data was accumulated to provide a basis for evaluating discrepant parts, to determine the effect of gross weight, to establish preliminary detection limits for parameters which had no available data, and to compare the character and value of parameters to the test cell, particularly vibration data.

During conduct of the discrepant implant tests, it became obvious that evaluation of the discrepant parts data base would be considerably improved if "no defect" baseline flights were conducted for each of the (same) components used for discrepant parts implant tests. These flights were conducted after the first portion of discrepant testing on the 3rd, 12th, 17th and 24th of May 1971. Because the transmission is a very time consuming component to replace in the aircraft, only one baseline transmission was tested with a set of "good" bearings.



- |        |  |
|--------|--|
| STEP 1 | GROUND EFFECT HOVER  |
| 2      | 500 FOOT CRUISE AT 70 KTS                                      |
| 3      | 1000 FT CRUISE AT 115 KTS                                      |
| 4      | CLIMB TO 10,000 FT (4,000 FT AFTER 2-10-71)<br>AT MAXIMUM RATE |
| 5      | 10,000 FT (4,000 FT) CRUISE AT 80 KTS                          |
| 6      | 10,000 FT (4,000 FT) CRUISE AT MAX SPEED                       |
| 7      | HOVER AT 10,000 FT (4,000 FT)                                  |
| 8      | DESCEND TO 500 FT AT 500 FT PER MIN AT 80 KTS                  |
| 9      | $N_2$ AT 6600 ON THE GROUND                                    |
| 10     | FLIGHT IDLE ON THE GROUND ( $N_1=70$ TO 72%)                   |

FIGURE 7-2 BASELINE FLIGHT PROFILE

Engine data as acquired in the test cell was obtained at 75 percent normal rated power, normal rated power, and at maximum rated power. These power levels, with the exception of 75 percent normal rated power, were seldom encountered during flight tests (see figure 7-3). In addition, the oil coolers in the test cell were a special part of the test cell and performed differently than that in the aircraft. These factors made correlation of engine parameters other than gas dynamics performance more difficult but not infeasible.

Early flight vibration data indicated the more complex nature of spectral energy when compared to the test cell. Since the ratio method of monitoring was being implemented based upon test cell data, modifications had to be made in order to account for the more complex spectrum. These changes were easily incorporated into the MRS mechanization.

Evaluation of engine gas dynamics performance was basically unchanged from the test cell. Correlation was good even though the power range was higher in the test cell. It is unfortunate, however, that the baseline accumulated for the four engines used for discrepant parts testing includes only the one series flown in May. The tear-down build-up cycle apparently has an effect on engine performance due to torque tolerances, etc. Consequently, additional baseline flights would have provided a better picture when considering the monitoring requirements of a normal service engine and would have improved the determination of baseline spread.

#### 7.7 DISCREPANT PARTS IMPLANT TESTS

The flight test data base is not as extensive as that of the test cell. Because of the amount of time involved in implanting discrepant parts in the aircraft's components, fewer test runs were made and degraded gears were not used. In addition to the normal service components of aircraft 67-17448, the data base contains results from the monitoring of four engines, four 90<sup>0</sup> gearboxes, and two 42<sup>0</sup> gearboxes. Part numbers of the components used for flight tests are shown in Table 7.3.

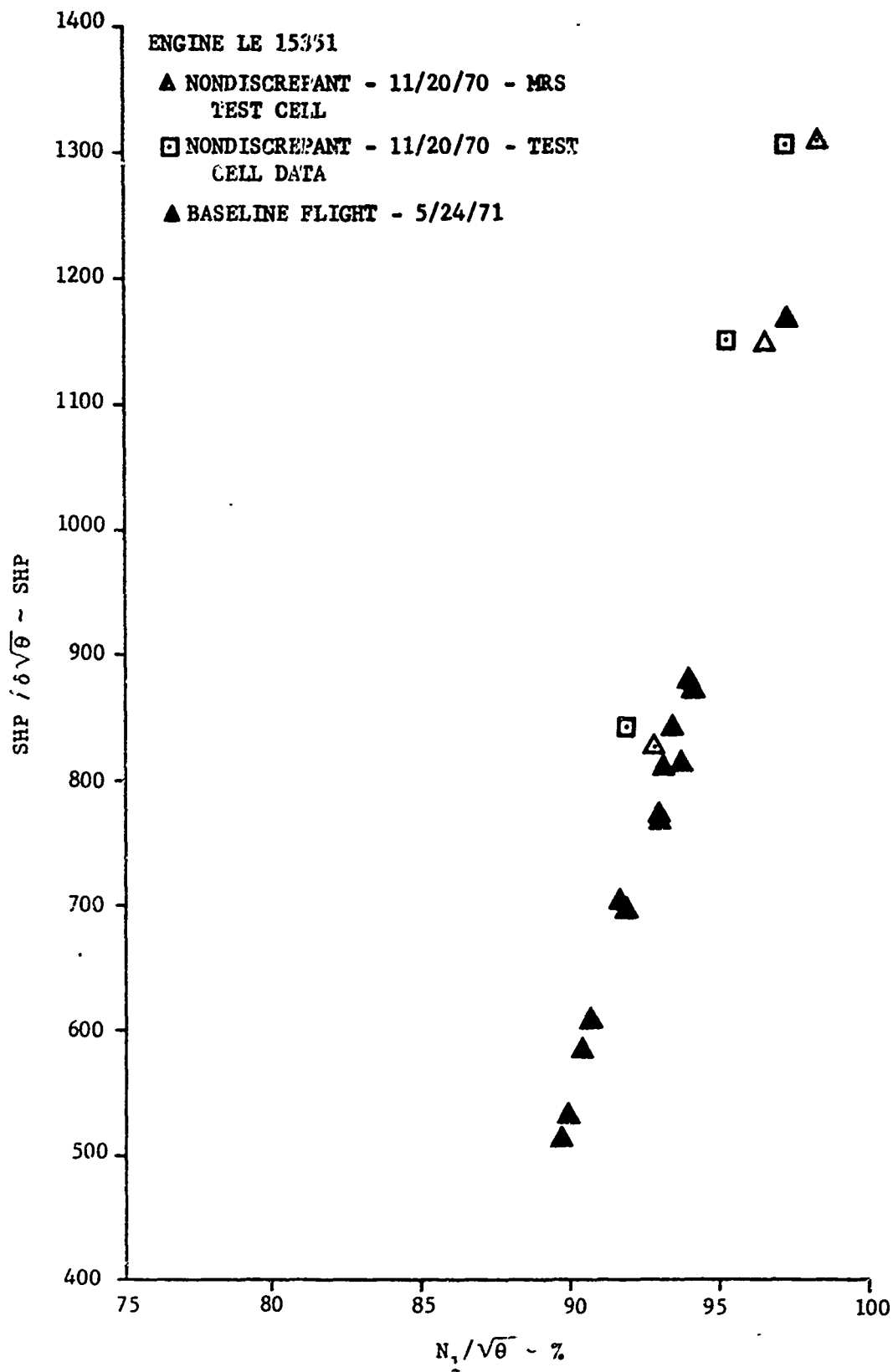


FIGURE 7-3 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

TABLE 7.3 COMPONENT PART NUMBERS

Engine	T53-L-13A
42° Gear Box	204-040-003-37
90° Gear Box	204-040-012-13
Transmission	204-040-016-1 & -5

Table 7.3 lists the flights and the serial number of parts which were discrepant and table 7.4 summarizes the types of discrepant. As in the case of baseline flights, data was recorded on the CIPR and on the Leach instrumentation recorder for direct and comparative evaluation.

TABLE 7.4 SUMMARY OF DISCREPANT PARTS

<u>FLIGHT DATA</u>	<u>NO. FLIGHTS</u>	<u>POWER COMPONENT S/N*</u>	<u>COMPONENT CONDITION</u>
1-18-71	1	Eng 18918	No defects
1-19-71	2	Eng 18918	No defects
2-17-71	2	Eng 15615	No. 2 bearing S/N 5724 out of tolerance.
		42° Gear Box B13-2925	Input ball bearing S/N 12463 fatigue pitted.
2-19-71	2	Eng 20727	No. 3 bearing S/N 1164 out of tolerance.
		42° Gear Box B13-5199	Input roller bearing S/N 124631 corrosive pitted inner race and roller.
2-24-71	2	Eng 15351	No. 4 bearing S/N 2652 out of tolerance.
		90° Gear Box ABC-142	Input ball bearing S/N 806K corrosion on balls and races.
2-26-71	2	Eng 18993	N1 nozzle S/N 9E-128 and 9F-007 sand-eroded and cracked.
		90° Gear Box A13-2065	Input roller bearing S/N 16805 rust pitted outer race and deep grooved roller.
3-3-71	1	Same as 2-24-71	Compressor S/N M-40453 F.O.D. and out of balance.
3-11-71	2	Eng 15615	Output ball bearing S/N E200-1 and -2 rust pitted and grooved balls.
		90° Gear Box A13-2772	Power turbine S/N 3888 and F5619 sand eroded and out of balance.
3-17-71 & 3-18-71	2	Eng 20727	Output roller bearing S/N 17522 fatigue pitted outer race and roller.
		90° Gear Box B13-6624	

\* Unless otherwise specified, the transmission serial number is A12-3159A, the mast assembly serial number A12-1799, the 42° gear box serial number is ABB-027, and the 90° gear box is B13-5388.

TABLE 7.4 (continued)

<u>FLIGHT DATA</u>	<u>NO. FLIGHTS</u>	<u>POWER COMPONENT S/N*</u>	<u>COMPONENT CONDITION</u>
3-23-71	3	Eng. 18918 Transmission	No defects. Input quill triplex ball bearing S/N K717 rusty balls and race.
3-25-71	2	Eng 18918 Transmission	No defects. Tail rotor output quill roller bearing S/N 11850 rusty pitted roller.
3-30-71	2	Eng 18918/Transmission	Mast bearing S/N 6739 corrosion pitted balls and inner race.
4-15-71 & 4-16-71	2	Eng 18993	N2 nozzles S/N 96005 and 9A054 burned and corroded.
4-26-71	2	42° Gear Box B13-5199  Eng 15351	Input roller bearing S/N 119953 rust pitted inner race and deep grooved rollers.  Bearing N. 4 S/N 984C corrosive pitted and I.C. over max (0.0043)
5-3-71	3	42° Gear Box B13-2925  Eng 20727 42° Gear Box ABB-289 90° Gear Box A13-2772 Mast Bearing 833E Tail rotor quill F12-6215 Input Quill Q12-520	Input ball bearing S/N 75104 rust corrosion damaged races and balls.  No defects. No defects No defects. No defects. No defects. No defects.
5-12-71	3	Eng 15615 42° Gear Box B13-2925 90° Gear Box A13-2065 Mast Bearing 198K Tail rotor quill F12-6277 Input Quill C12-1341	No defects. No defects. No defects. No defects. No defects. No defects.

TABLE 7.4 (cont inued)

<u>FLIGHT DATA</u>	<u>NO. FLIGHTS</u>	<u>POWER COMPONENT S/N*</u>	<u>COMPONENT CONDITION</u>
5-11-71	2	Eng 18993 42° Gear Box B13-8304 90° Gear Box ABC-142 Main Bearing 67 Tail Rotor Quill B12-55524 Input Quill CP12-4268	No defects. No defects. No defects. No defects. No defects. No defects.
5-24-71	2	Eng. 15351 42° Gear Box B13-5199 90° Gear Box B13-6624 Main Bearing 612J Tail Rotor Quill B12-18628 Input Quill CP12-7105	No defects. No defects. No defects. No defects. No defects. No defects.
5-27-71	2	Eng 15615	No. 2 bearing S/N 5357 corrosive pitted outer race and roller; excessive roller end wear.
6-3-71 & 6-4-71	2	90° Gear Box A13-2772 Eng 20727	Input ball bearing S/N 8017E grooves on balls. No. 3 bearing S/N 1025 pitted outer race; excessive end wear.
6-10-71	2	90° Gear Box ABC-142 Eng 18993	Input roller bearing S/N 2929 rust pitted outer race and grooved and pitted rollers Compressor S/N M-42476 F.O.D. and out of balance.
6-14-71	2	90° Gear Box B13-6624 Eng 15351	Output ball bearing S/N 29745 fatigue pitted balls (rough) Power turbine S/N (T.B.D.) warped and out of balance.
6-11-71	2	90° Gear Box A13-2065 Eng 15615	Output roller bearing S/N 28418 rust pitted rollers and corrosive pitted outer race. N1 nozzles S/N 7C157 & C-40 sand eroded.

TABLE 7.4 (continued)

<u>FLIGHT DATA</u>	<u>NO. FLIGHTS</u>	<u>POWER COMPONENT S/N*</u>	<u>COMPONENT CONDITION</u>
6-21-71	2	Eng 20727	N2 nozzles S/N (T.B.D.) sand eroded and warped.
6-28-71	2	Eng 18918	Droop misadjusted on second flight.
6-29-71	-	Eng 18918	Ground run-up with fuel control misadjusted.
7-1-71	2	Eng 18918	No defects.
		Mast Assembly	Bearing S/N 465 corrosive pitted inner and outer races and balls (5 each).
7-6-71	2	Eng 18918	No defects.
		Transmission Tail Rotor Quill B12-18628	Tail rotor quill, roller bearing S/N 12591 corrosive inner race and rollers.
7-8-71 & 7-9-71	2	Eng 18918	No defects.
		Transmission Input Quill CP12-7105	Input quill bearing S/N L357 pitted outer race.

### 7.7.1 VIBRATION

Vibration monitoring during discrepant parts testing was concerned with correlating the discrepant implant to the established ratio detection method mechanized in the EU. Correlation involved analysis of power spectral density plots (PSD's) obtained during discrepant parts flights. Both the ratios mechanized in the EU and other ratios established for accelerometer data, recorded on the Leach instrumentation recorder, were used for the analysis. In addition, the effectiveness of the ratio method was evaluated and the effect of the flight mode was investigated. Analysis of data from early flight tests (primarily baseline) indicated the more complex spectra of the monitored components than observed in the test cell. Coupling between components (drive couplings), different mountings, and different dynamic loadings account for the differences. As a result of the differences, the filter bands used in the test cell were changed for monitoring circuits used in the flight tests. These changes were incorporated into the VSA circuits which replaced the single frequency narrow-band circuits used in the test cell and early flight tests.

#### 7.7.1.1 Flight Data Filter Bands

Table 7.5 lists the band used for detection of abnormal gear boxes and transmissions.

TABLE 7.5 FREQUENCY BANDS FOR GEAR BOXES AND TRANSMISSION

Component	Band 1 (Hz)	Band 2 (Hz)	Accelerometer
90° Gear Box	3415 → 4000	4430 → 5000	Lateral
42° Gear Box	2750 → 3050	4250 → 4600	Longitudinal
Transmission	2630 → 3530	3560 → 5000	Normal Mast

Bands used for the spectral vector technique of engine monitoring used with the original VSA are listed in table 7.6.

TABLE 7.6 SPECTRAL VECTOR FREQUENCY BANDS FOR ENGINE COMPRESSOR ACCELEROMETER

Reference Band (Hz)	Band 1 (Hz)	Band 2 (Hz)
77 to 126	2095 to 3350	3540 to 5000

Even though the MRS hardware was being flown with a fixed relationship of bands and ratios, analysis of flight data using PSD's allowed a constant back-up and evaluation of the mechanization. As the data base increased during the program and baseline data of discrepant components was acquired during May, results of analysis were less consistent when the wider (more divergent) baselines were considered.

In June 1971, the engine vibration data base was reviewed in order to better accommodate a more divergent baseline of engines. It was found that the combustor accelerometer gave more consistent results than either the turbine or previously used compressor accelerometer. Table 7.7 lists the frequency bands used in the analysis of the engine combustor accelerometer.

TABLE 7.7 ENGINE COMBUSTOR FILTER BANDS

(Hz)	BAND A	BAND B	BAND C	BAND D	BAND E	BAND F
From	605	755	955	1670	2070	2270, 2340*
To	695	875	1270	1890	2180	2660
*: REVISED LOWER LIMIT						

Various combinations of ratios were utilized to provide fault isolation; e.g., Band "B" divided by Band "A" was sensitive to nozzles while Band "F" divided by Band "D" was sensitive to bearings and compressors. The (more general) spectral vector method did not satisfy monitoring requirements as expected, so the ratio method was incorporated instead of the spectral vector (a ratio is a special case of the spectral vector). Present mechanization limitations allowed only Bands F and D to be mechanized.

#### 7.7.1.2 Effectiveness of Ratio Method

Because of the previously mentioned change in the spectra of flight data relative to that of the test cell, evaluation of the effectiveness of the ratio method was a basic consideration, particularly when compared to the previously implemented single frequency narrow band technique of monitoring. The effectiveness of the ratio method is demonstrated by consideration of its sensitivity to a discrepant (abnormal) condition and how the sensitivity varies relative to flight condition.

Figure 7-4 illustrates the measured ratios for the Engine Combustor Accelerometer for all 10 steps of the flight envelope (see section 7.6 for flight profile). Note that the ratios for very low power levels (steps 9 and 10) do not differ appreciably from the high power levels. Figure 7-5 illustrates the anomalies results obtained from the same data. The vertical scale in figure 7-5 has been adjusted so that step 2 has the same value as the step 2 in figure 7-4. Note how unnormalized data follows the power settings of the aircraft, while the ratio method remains relatively indifferent. The ratio of the minimum value to the maximum value for figure 7-4 is only 3:1 while figure 7-5 is almost 25:1. The mean level in figure 7-4 is 3.0, with a peak-to-peak variance of 3. The mean level of figure 7-5 is 2.6, with a peak-to-peak variance of 5.75. Figure 7-6 graphically illustrates this point.

Figures 7-7 and 7-8 illustrate a grossly degraded FOD compressor (note the change in vertical scale). The average value is 16 for the ratio method compared to 11 for the unnormalized method. The unnormalized method is capable of detecting this discrepant compressor, but not as well as the ratio method -- had it not been for step 1, the unnormalized method may not have been able to detect the compressor.

A natural question arises from the comparison of figure 7-7 with figure 7-8 -- why should a ratio be more sensitive to failures than simple threshold detection? The exact mechanics of the "why" are not well understood, but the general feeling is that the bands in the ratio method are not statistically independent. The two bands are coupled to each other through the complex (non-linear) dynamics of the machine. The effect is much like a teeter-totter -- as the machine starts to fail, the upper band increases while the lower band decreases.

The ratio of the two frequency bands can be considered to be a dimensional transformation; i.e., the two frequency dimensions are transformed into one ratio dimension. The individual statistics (the mean and the variance) of the frequency bands may be identical, while the statistics of the ratio may differ considerably. Figure 7-9 helps illustrate this point. It shows the dependence of the two bands and why the ratio variances tend to be lower. As power level changes, the absolute value in each band tends to move in the

# VIBRATION LEVELS AS A FUNCTION OF FLIGHT PROFILE

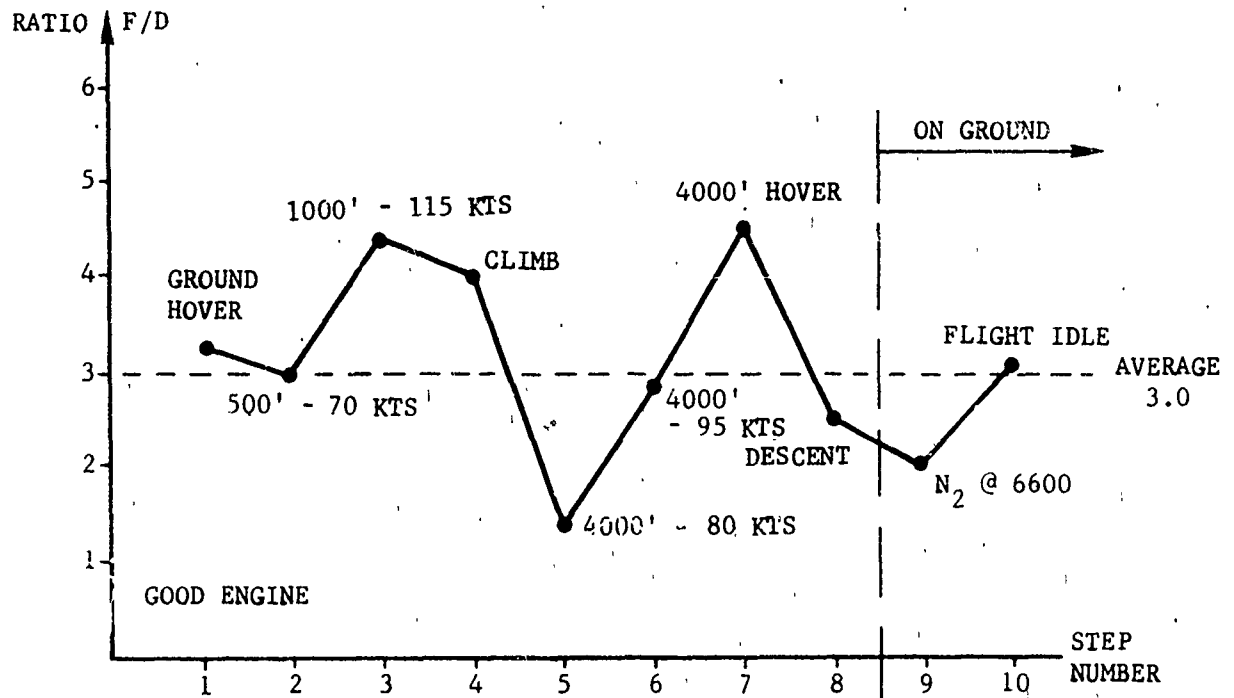


FIGURE 7-4 RATIO F/D AS A FUNCTION OF FLIGHT PROFILE

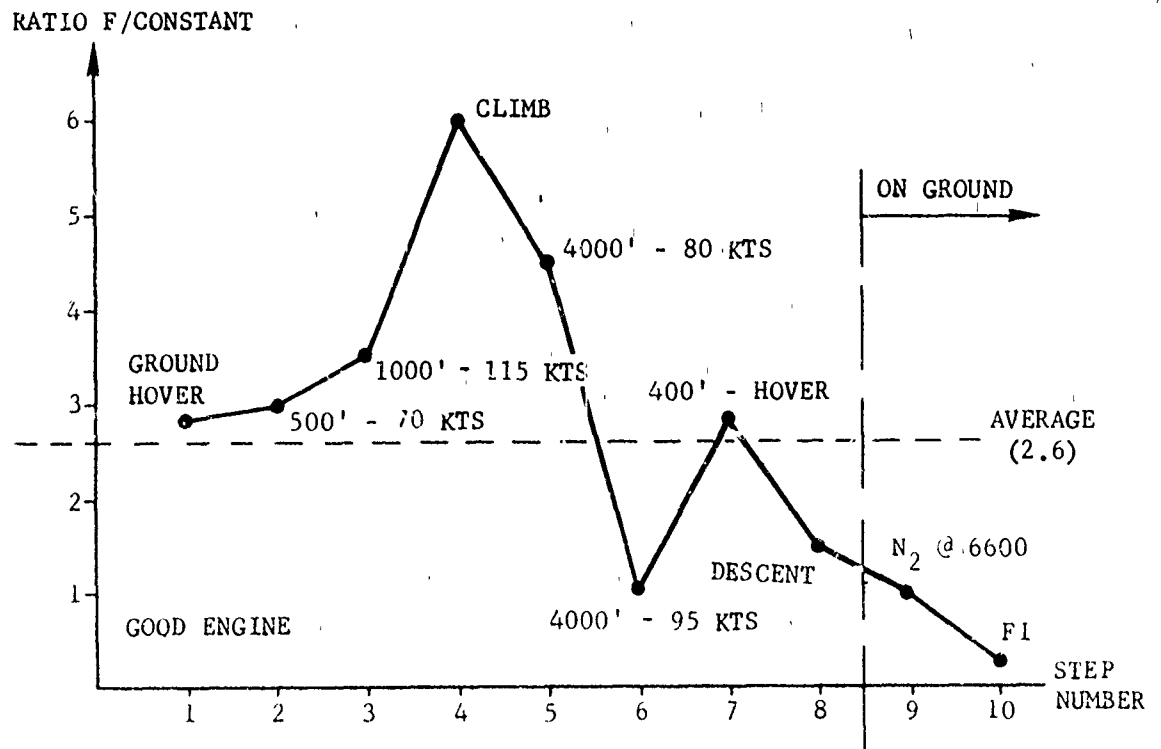


FIGURE 7-5 UN-NORMALIZED VALUES OF BAND "F"

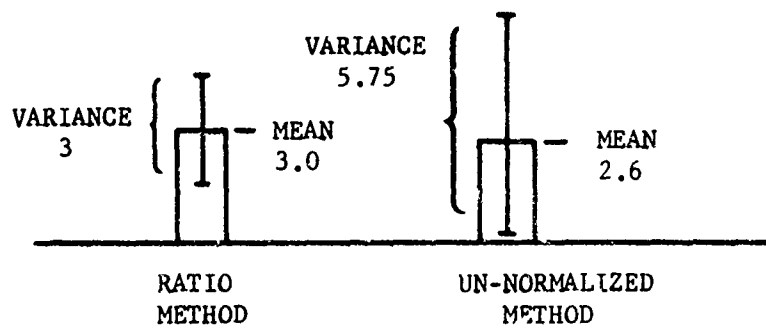


FIGURE 7-6 COMPARISON OF THE MEAN AND VARIANCE FOR THE RATIO METHOD VERSUS THE UN-NORMALIZED METHOD - GOOD ENGINE

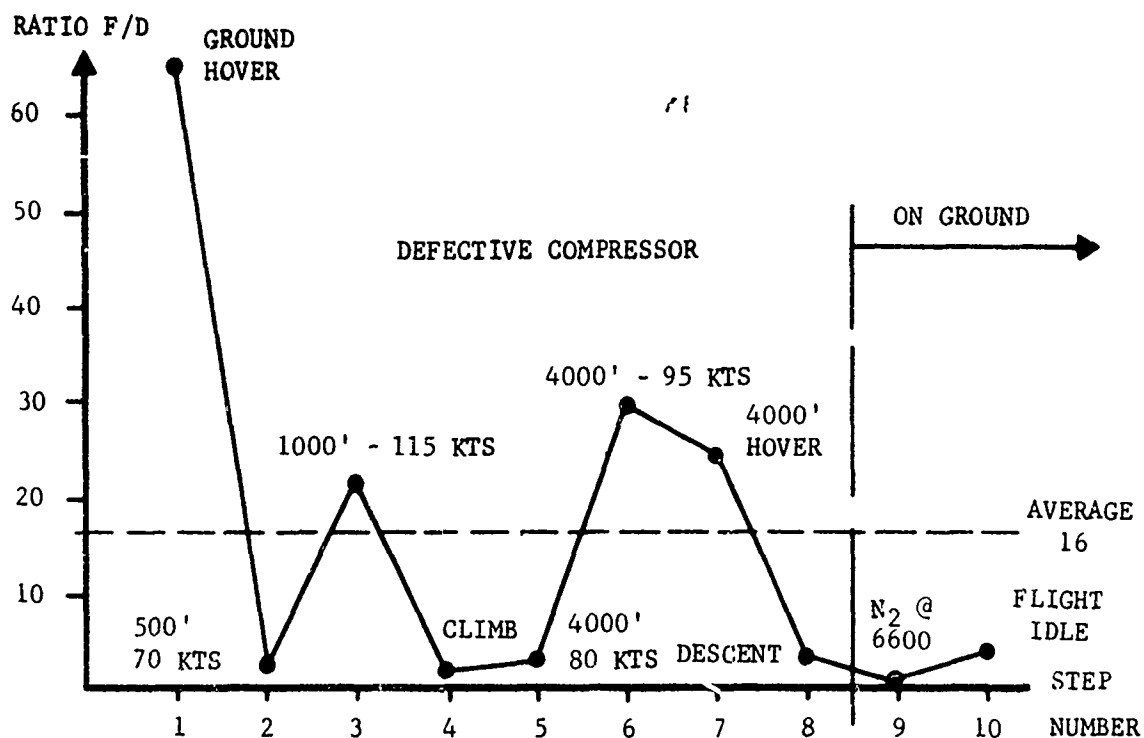


FIGURE 7-7 VIBRATION LEVELS FOR DEFECTIVE COMPRESSOR

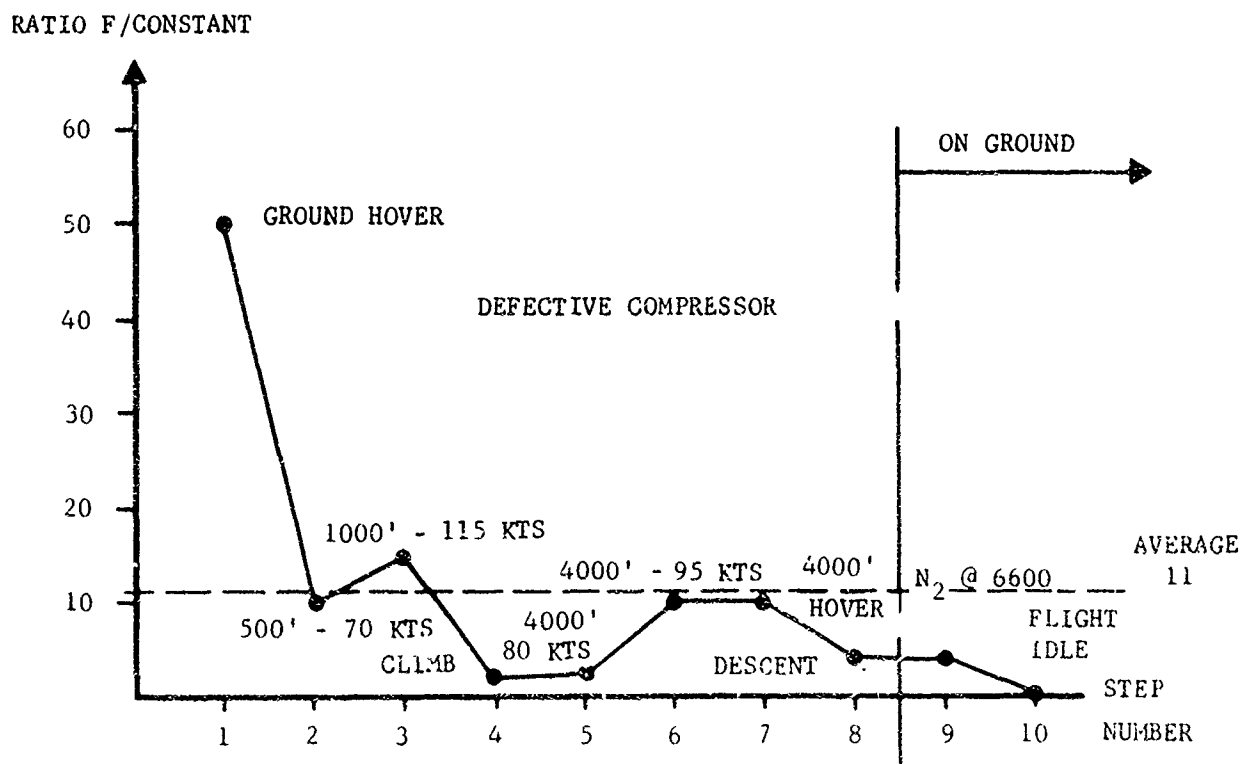


FIGURE 7-8 UN-NORMALIZED VIBRATION LEVELS FOR DEFECTIVE COMPRESSOR

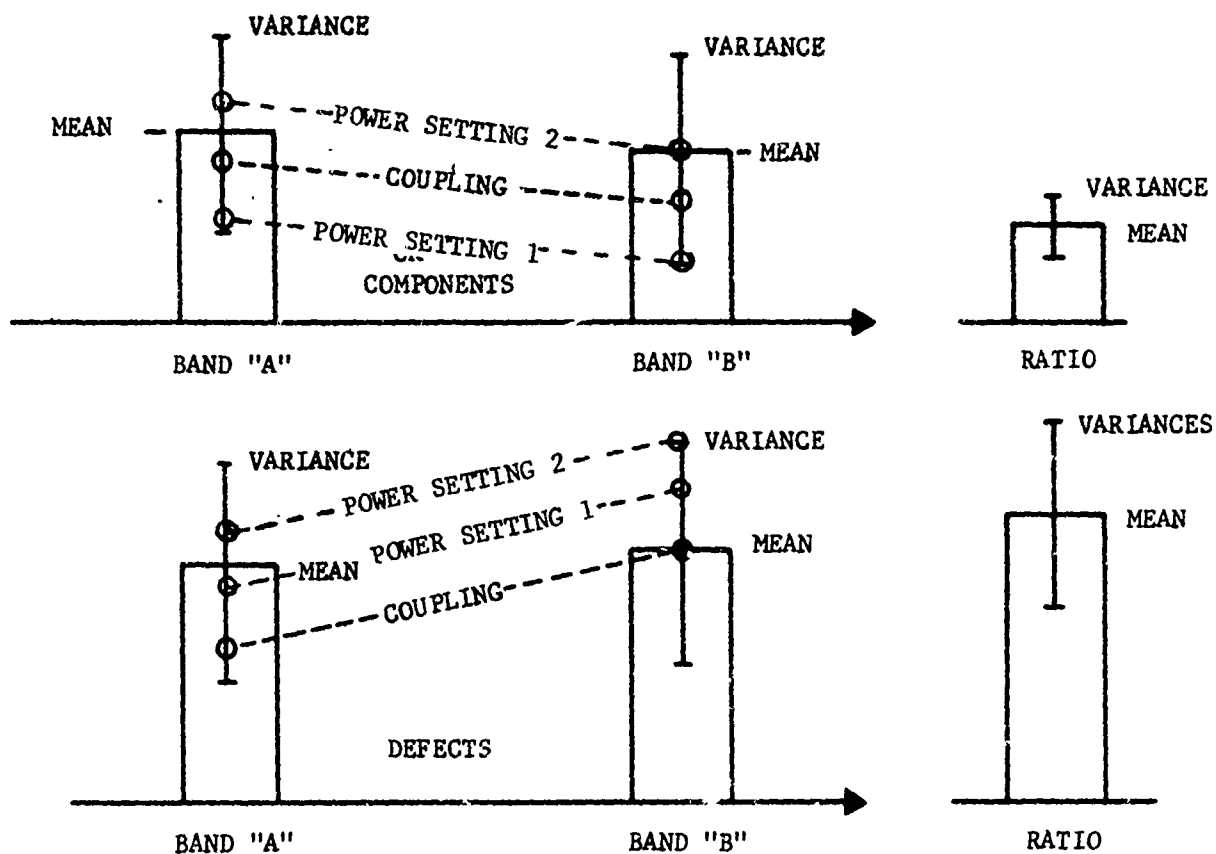


FIGURE 7-9 COUPLING EFFECTS

same direction (i.e., there is correlation). Hence, the variation of the ratio tends to be lower than the individual variations and more indicative of actual component condition.

The top illustration in figure 7-9 shows how bands A and B might be coupled in a baseline unit. When the statistics of Band A of a baseline machine are compared with the statistics of Band A of a defective machine, there appears to be little correlation. The same is true for Band B. Threshold detection is of limited use here because the variances overlap excessively. However, if the ratio is taken before the statistics are compared, a significant difference between the means exists and the variances do not overlap appreciably. The purely statistical approach fails because the bands are not statistically independent. The ratio method works because the ratio transforms the statistically interrelated bands into a statistically determinant form. This is verified throughout the course of the program where the ratios selected are invariably a high frequency band over a low frequency band. As the number (ratio) gets larger, the energy is being transferred from the lower band to the higher band, thus indicating a degradation in component health. When one examines the individual bands, it is seen that their energy is frequently random and at best a less sensitive indicator of component health.

#### 7.7.1.3 PSD Analysis

During the conduct of the flight test, many recordings were made of discrepant and no defect components. Typical PSD's which exemplify the tests conducted and show the consideration involved in utilizing the accumulated data have been included. Both baseline and discrepant parts PSD examples are summarized in table 7.8 and in figures 7-10 through 7-31.

The ability to establish detection criteria is shown in figures 7-32 through 7-36. Bands and ratios used in each figure are the same as that mechanized in the MRS, except Figure 7-33, which represents the B/A ratio used for analysis only. For the sake of clarity, data acquired from only one step of the discrepant profile is presented in the figures.

Separation of the discrepant implants from the no defect baseline was excellent and the utility of the mechanization criteria is quite evident. The ability to discriminate 42° gearbox faults is, however, not as good as depicted in figure 7-33. During the latter part of discrepant implant flight tests,

TABLE 7.8 PSD PLOT INDEX

VIBRATION PICKUP	FAULT	FLIGHT MODE	COMMENTS	FIGURE
90° G.B. Lateral	No Discrepancy	Ground Hover	Light Weight	7-10
	Input Roller	Ground Hover	S/N A13-2065	7-11
	Output Roller	Climb	S/N B13-6624	7-12
	Input Ball	Hover	S/N A13-2772	7-13
	Output Ball	Climb	S/N B13-6624	7-14
	Mounted Wrong	Climb	S/N A13-2065	7-15
42° G.B. Longitudinal	No Discrepancy	Ground Hover	S/N ABB-027	7-16
	Input Roller	Ground Hover	S/N B13-5199	7-17
	Input Ball	Ground Hover	S/N B13-2925	7-18
	90° G.B. Mounted Wrong	Ground Hover	S/N B13-2925	7-19
Transmission Normal Mast	No Discrepancy	Ground Hover	Light Weight	7-20
	No Discrepancy	Ground Hover	Medium Weight	7-21
	No Discrepancy	Ground Hover	Maximum Weight	7-22
	Tail Rotor Output	Climb	S/N 11850	7-23
	Quill Bearing			
	Mast Bearing	Ground Hover	S/N 6739	7-24
	Input Quill Triplex Bearing	Ground Hover	S/N K-717	7-25
Engine Combustor	No Discrepancy	Ground Hover	S/N 14819	7-26
	#2 Bearing	Ground Hover	S/N 15615	7-27
	#3 Bearing	Ground Hover	S/N 20727	7-28
	#4 Bearing	Ground Hover	S/N 15351	7-29
	N <sub>1</sub> Nozzle	Ground Hover	S/N 18993	7-30
	N <sub>2</sub> Nozzle	Ground Hover	S/N 18993	7-31

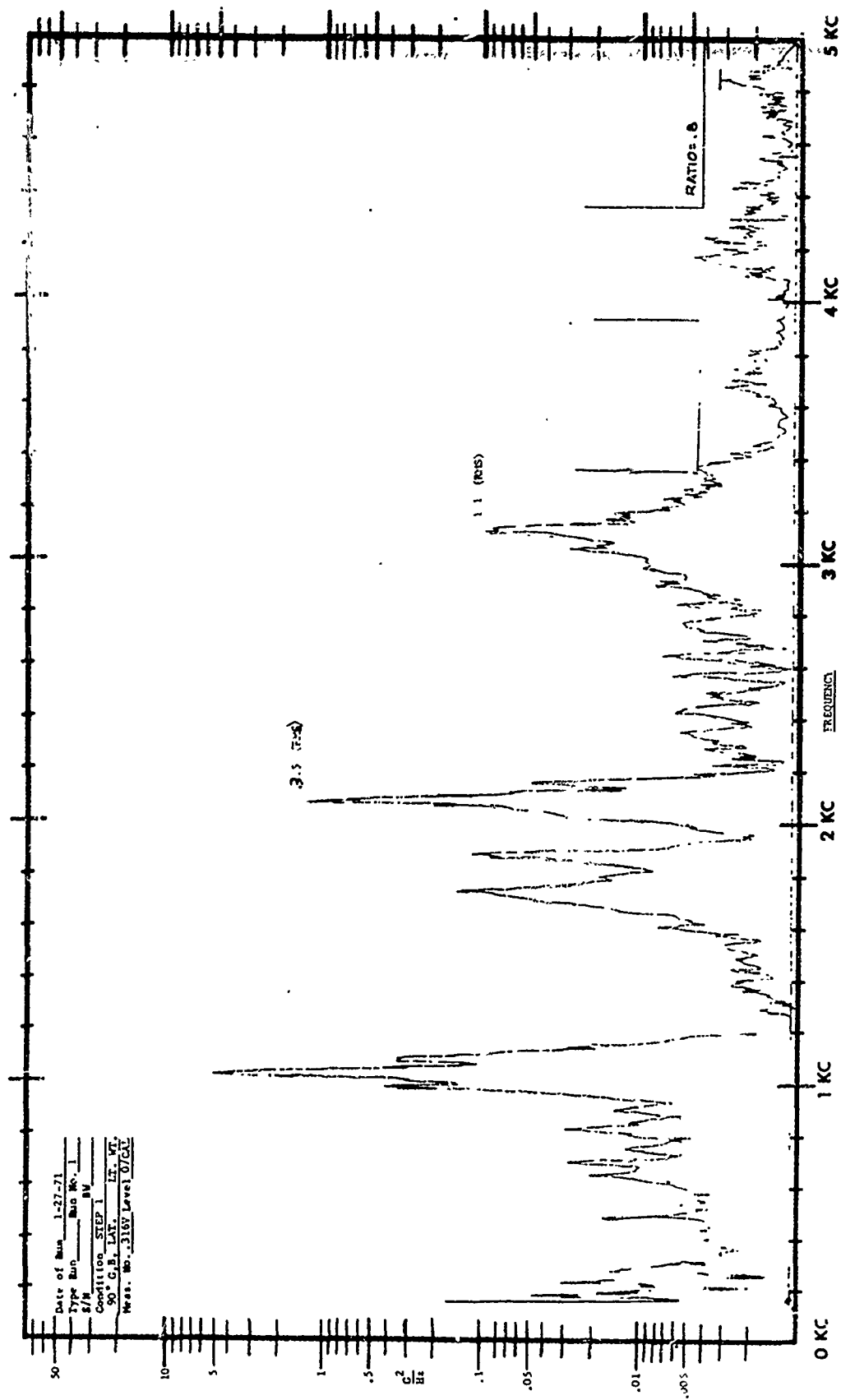


FIGURE 7-10 90° GEARBOX LATERAL, 1/27/71, GROUND HOVER, NO DEFECTS, LIGHTWEIGHT

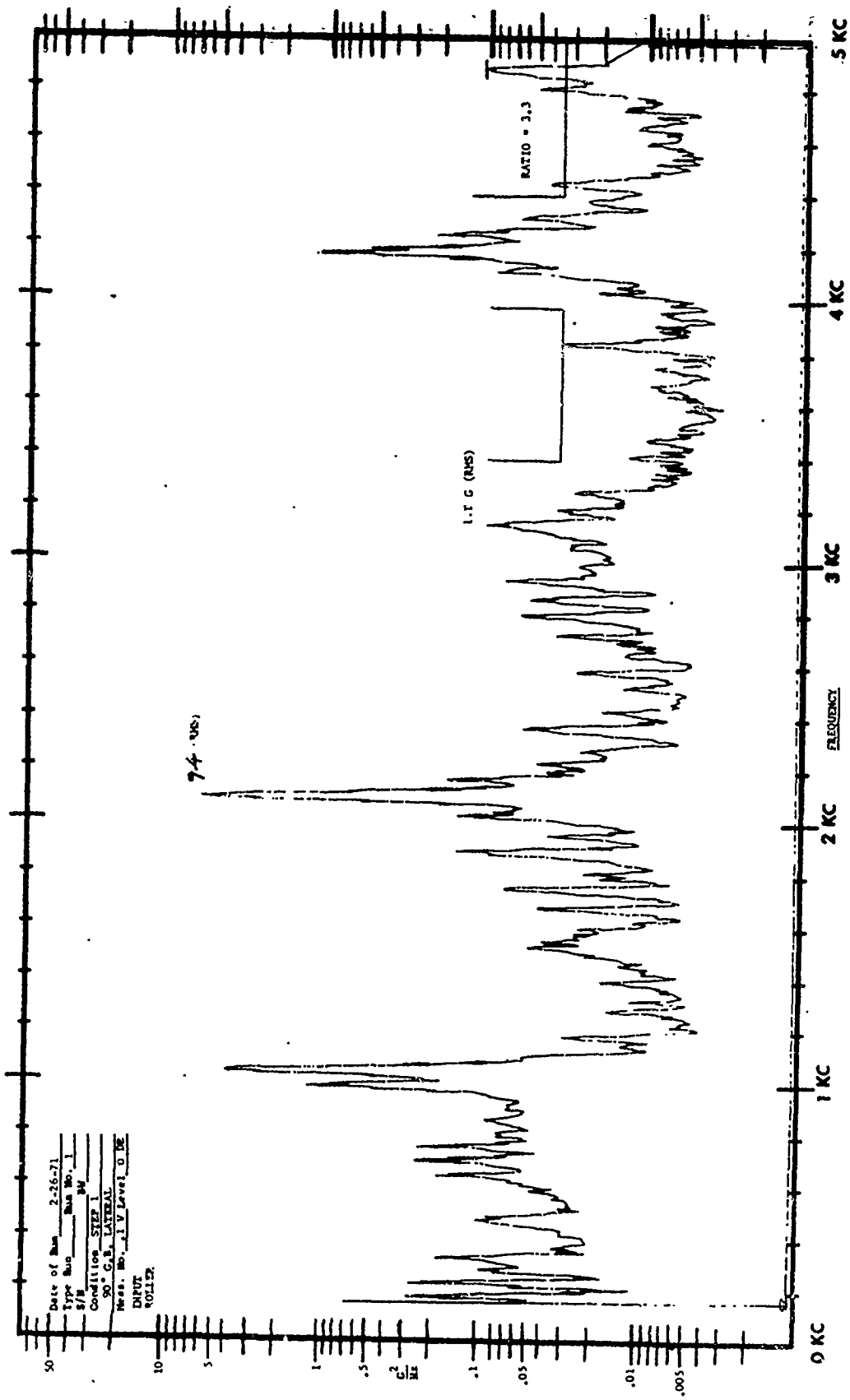


FIGURE 7-11 90° GEARBOX LATERAL, S/N A13-2065, 2/26/71,  
GROUND HOVER, DISCREPANT INPUT ROLLER BEARING

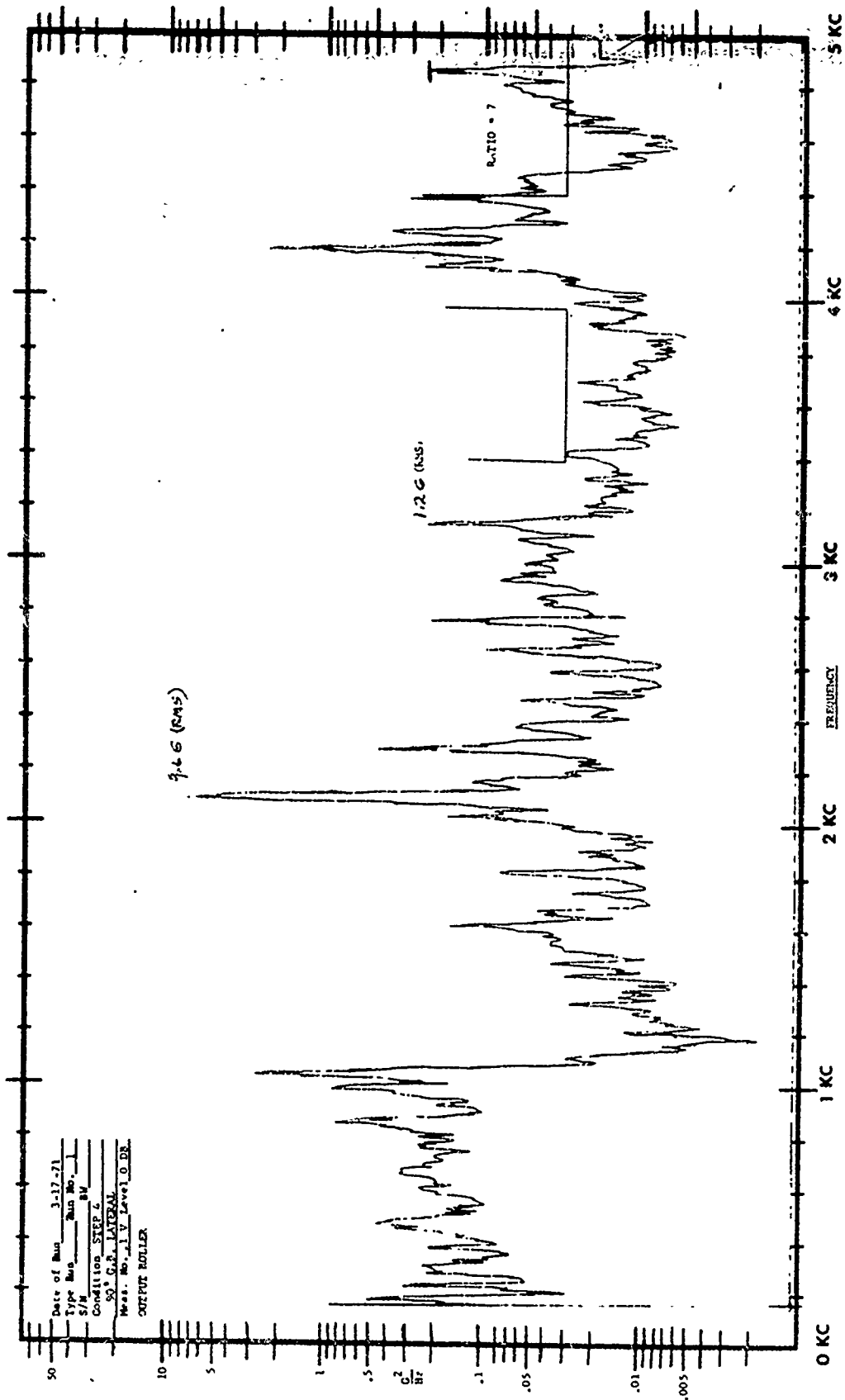


FIGURE 7-12 90° GEARBOX LATERAL, S/N B13-6624, 3/17/71, CLIMBING, DISCREPANT OUTPUT ROLLER BEARING

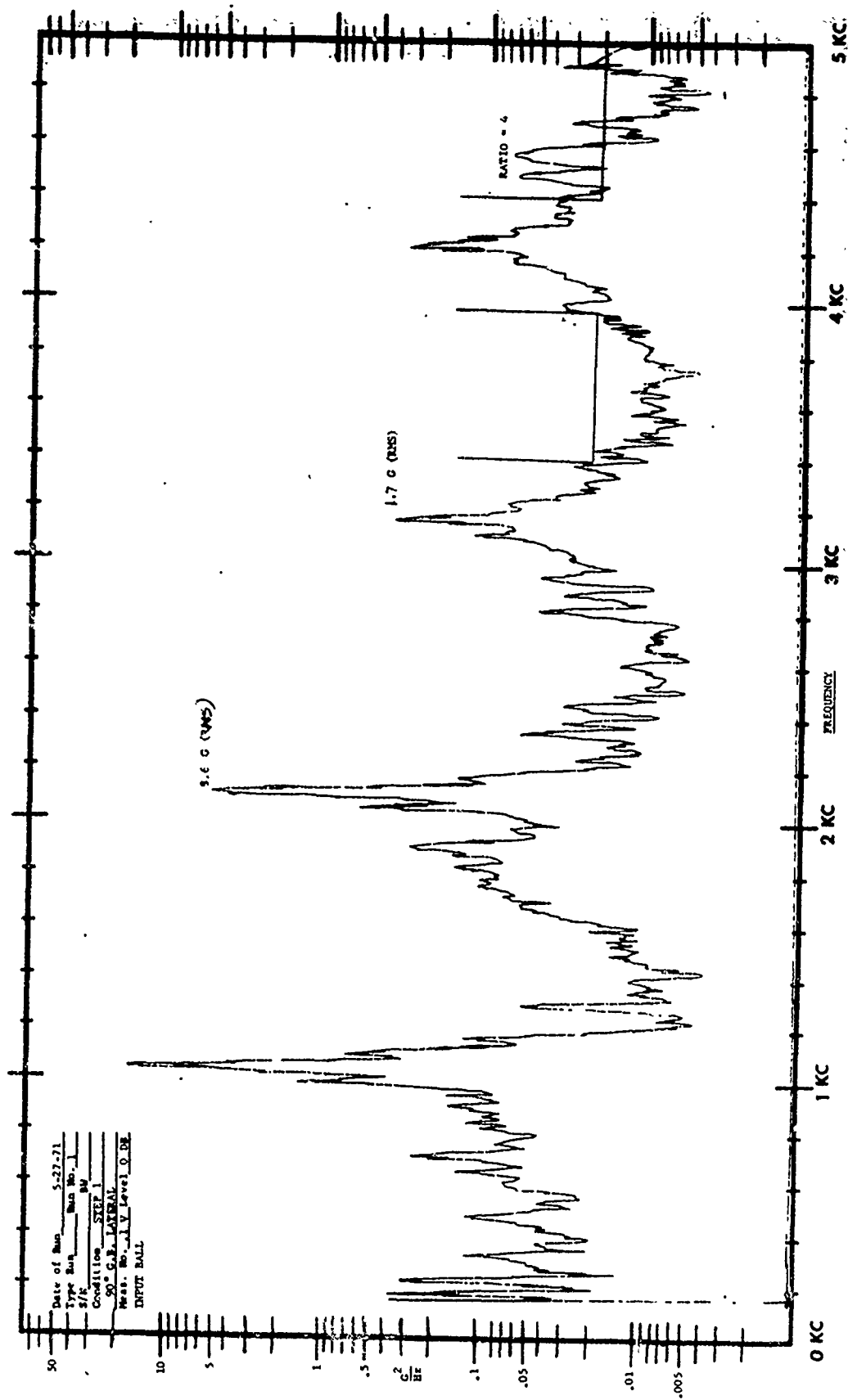


FIGURE 7-13 90° GEARBOX LATERAL, S/N A13-2772, 5/27/71,  
HOVERING, DISCREPANT INPUT BALL BEARING

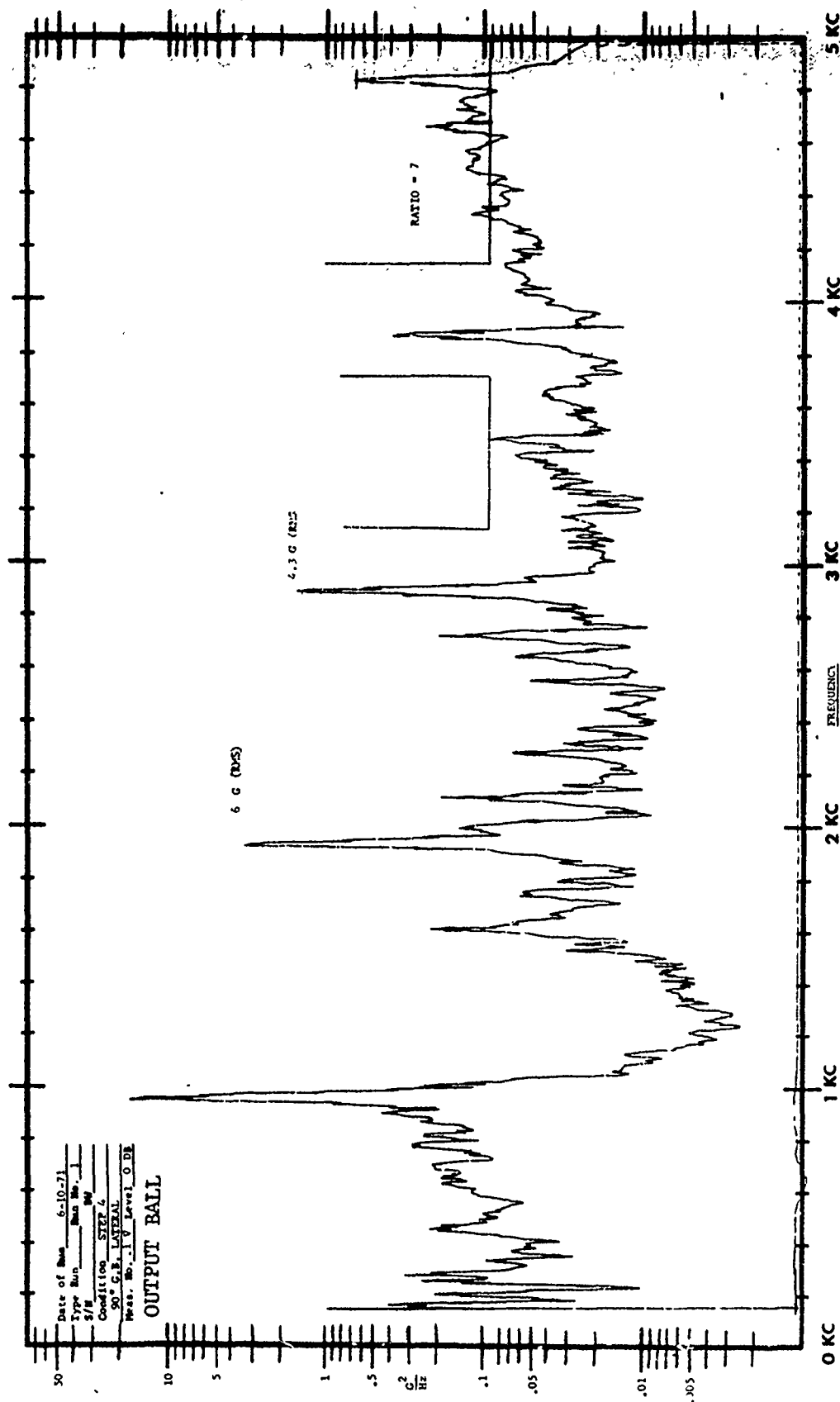


FIGURE 7-14 90° GEARBOX LATERAL, S/N B13-6624, 6/10/71  
CLIMBING, DISCREPANT OUTPUT BALL BEARING

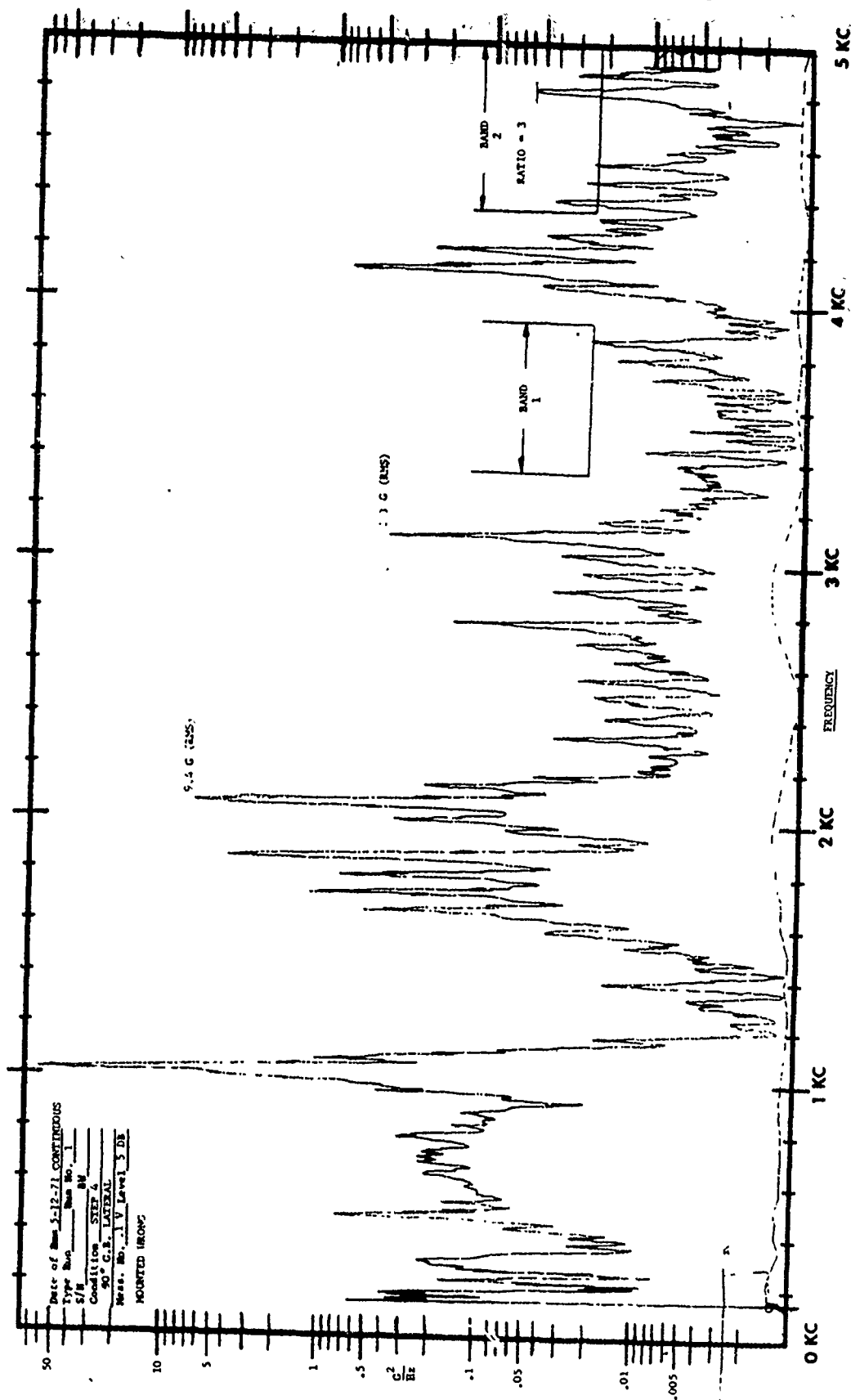


FIGURE 7-15 90° GEARBOX LATERAL, S/N A13-2065, CLIMBING, MOUNTED WRONG

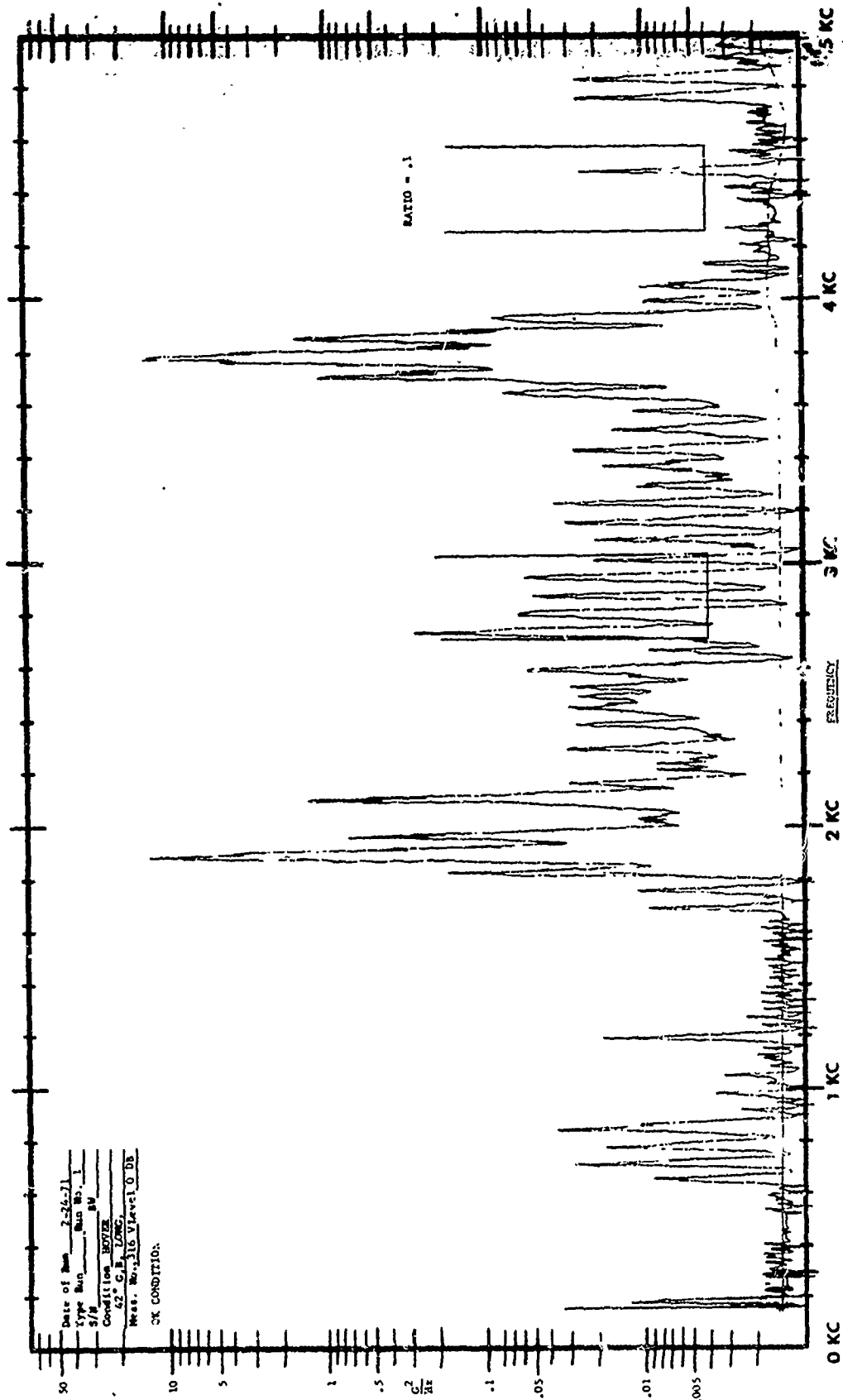


FIGURE 7-16 42° GEARBOX LONGITUDINAL, S/N ABB-027,  
2/24/71, GROUND HOVER, NO DEFECTS

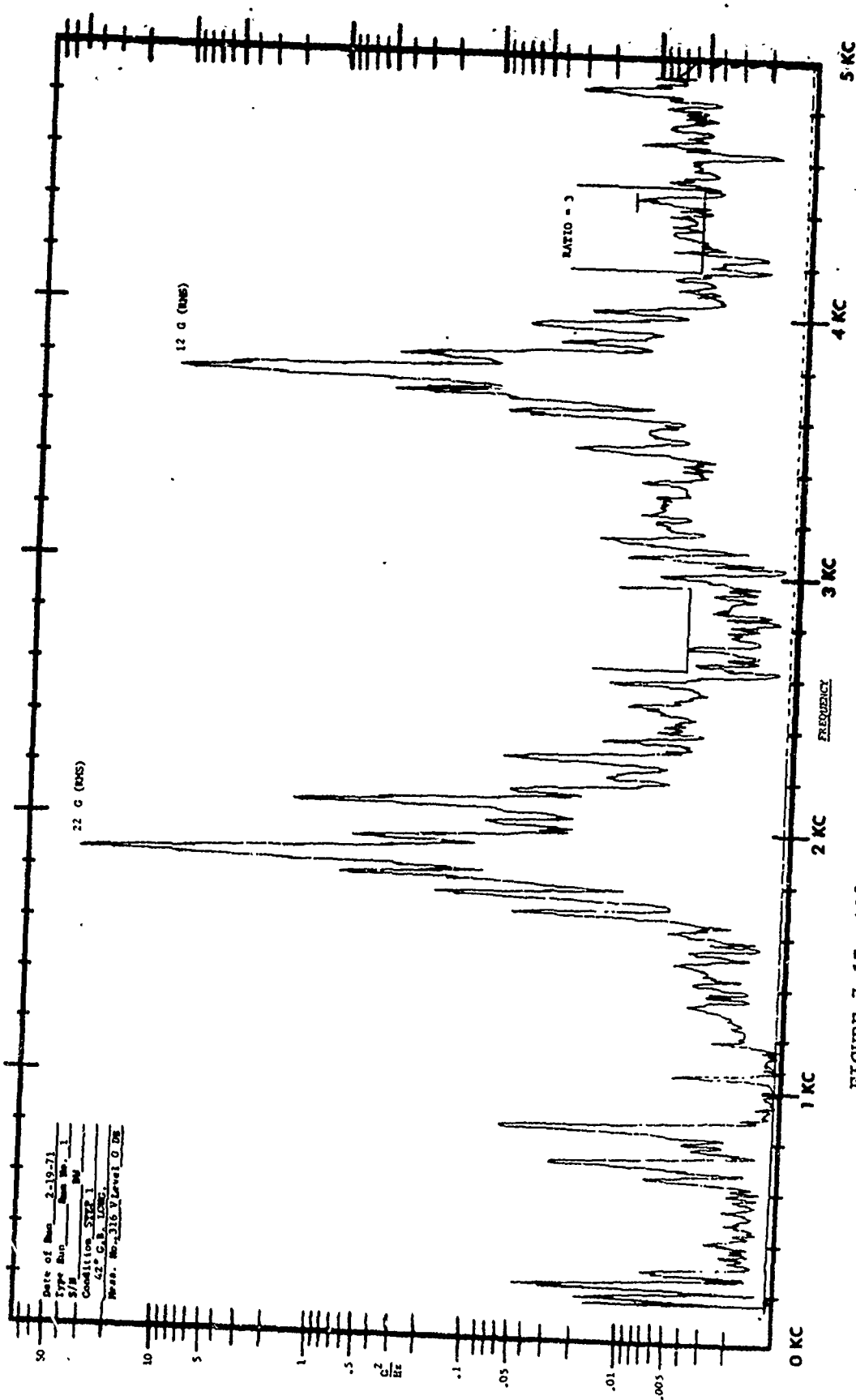


FIGURE 7-17 42° GEARBOX LONGITUDINAL, S/N B13-5199, 2/19/71,  
 GROUND HOVER, DISCREPANT INPUT ROLLER BEARING

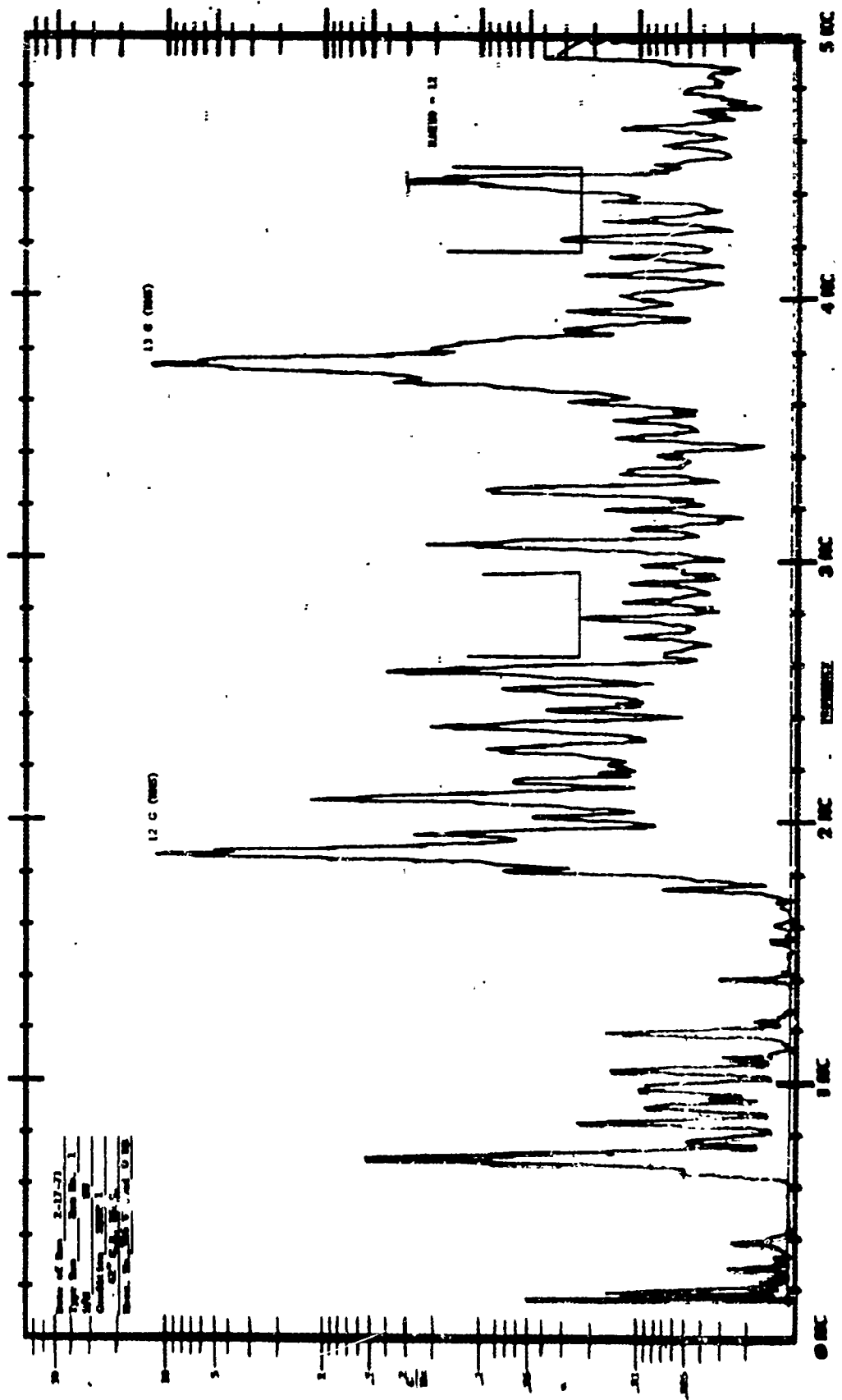


FIGURE 7-16 42° GEARBOX LONGITUDINAL, S/N B13-2925, 2/17/71.  
GROUND HOVER, DISCREPANT INPUT BALL BEARING

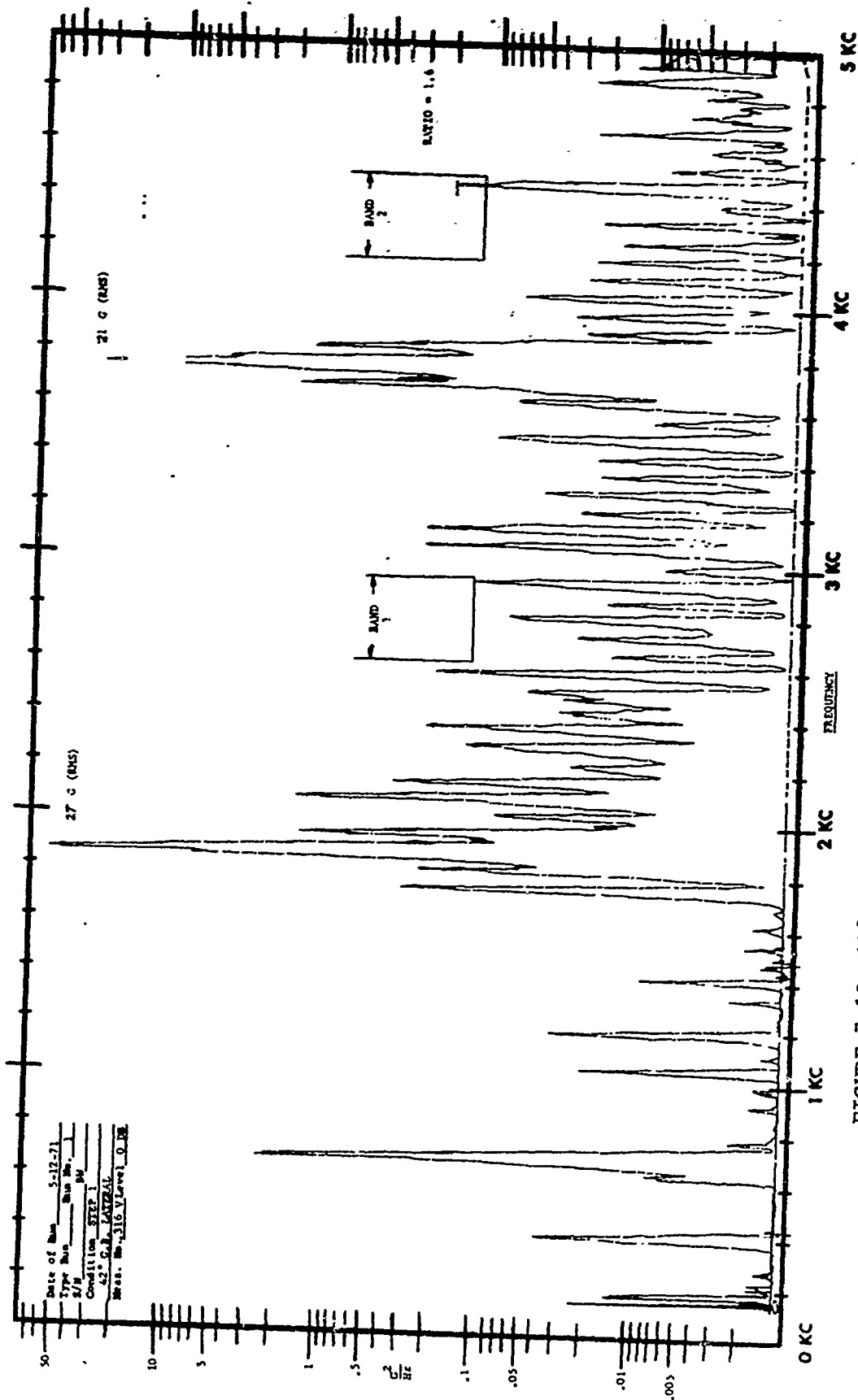


FIGURE 7-19 42° GEARBOX LONGITUDINAL, S/N B13-2925, 5/12/71  
GROUND HOVER, 90° GEARBOX MOUNTED WRONG

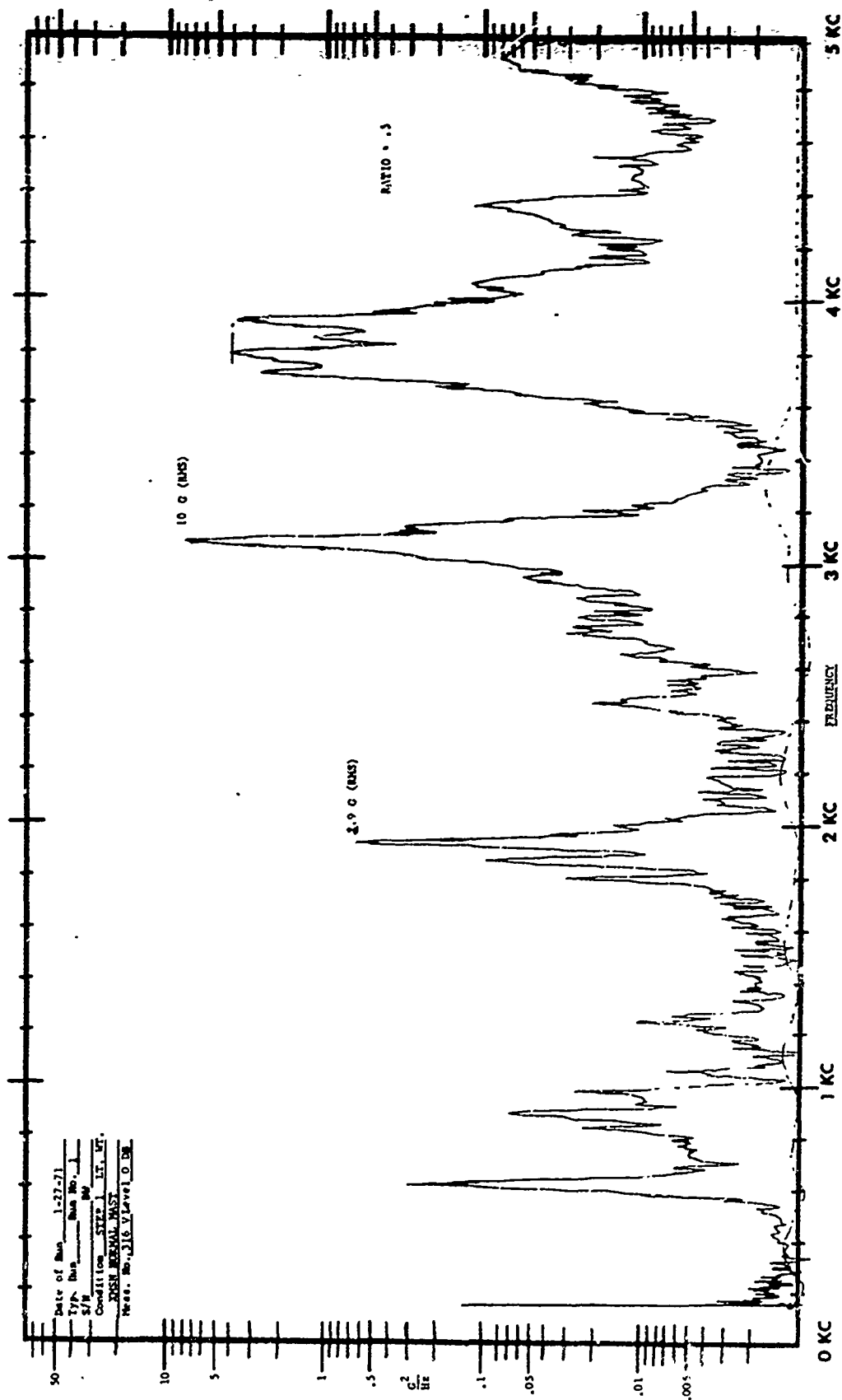


FIGURE 7-20 TRANSMISSION NORMAL MAST, 1/27/71,  
GROUND HOVER, NO DEFECT, LIGHTWEIGHT

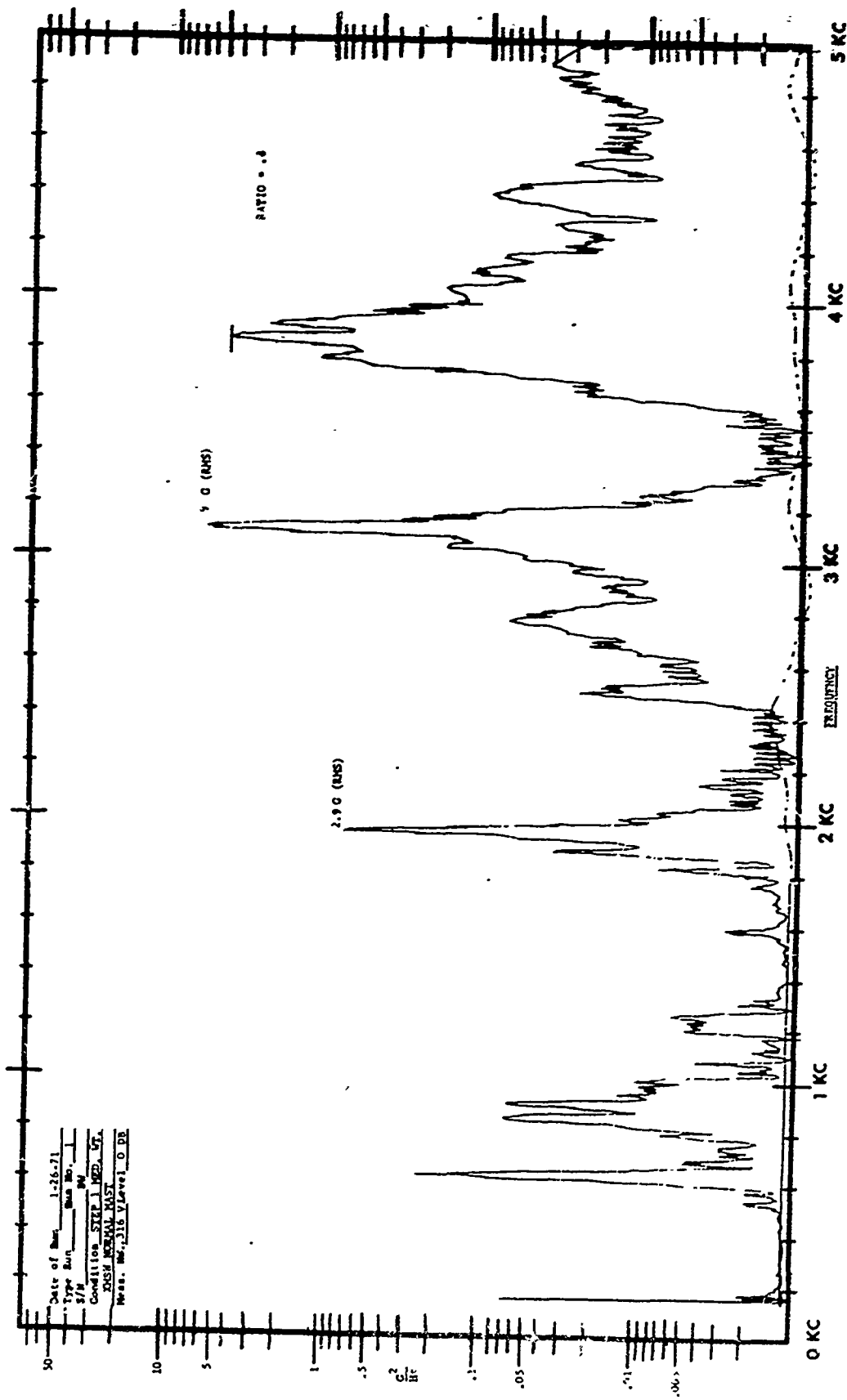


FIGURE 7-21 TRANSMISSION NORMAL MAST, 1/26/71,  
GROUND HOVER, NO DEFECTS, MEDIUM WEIGHT



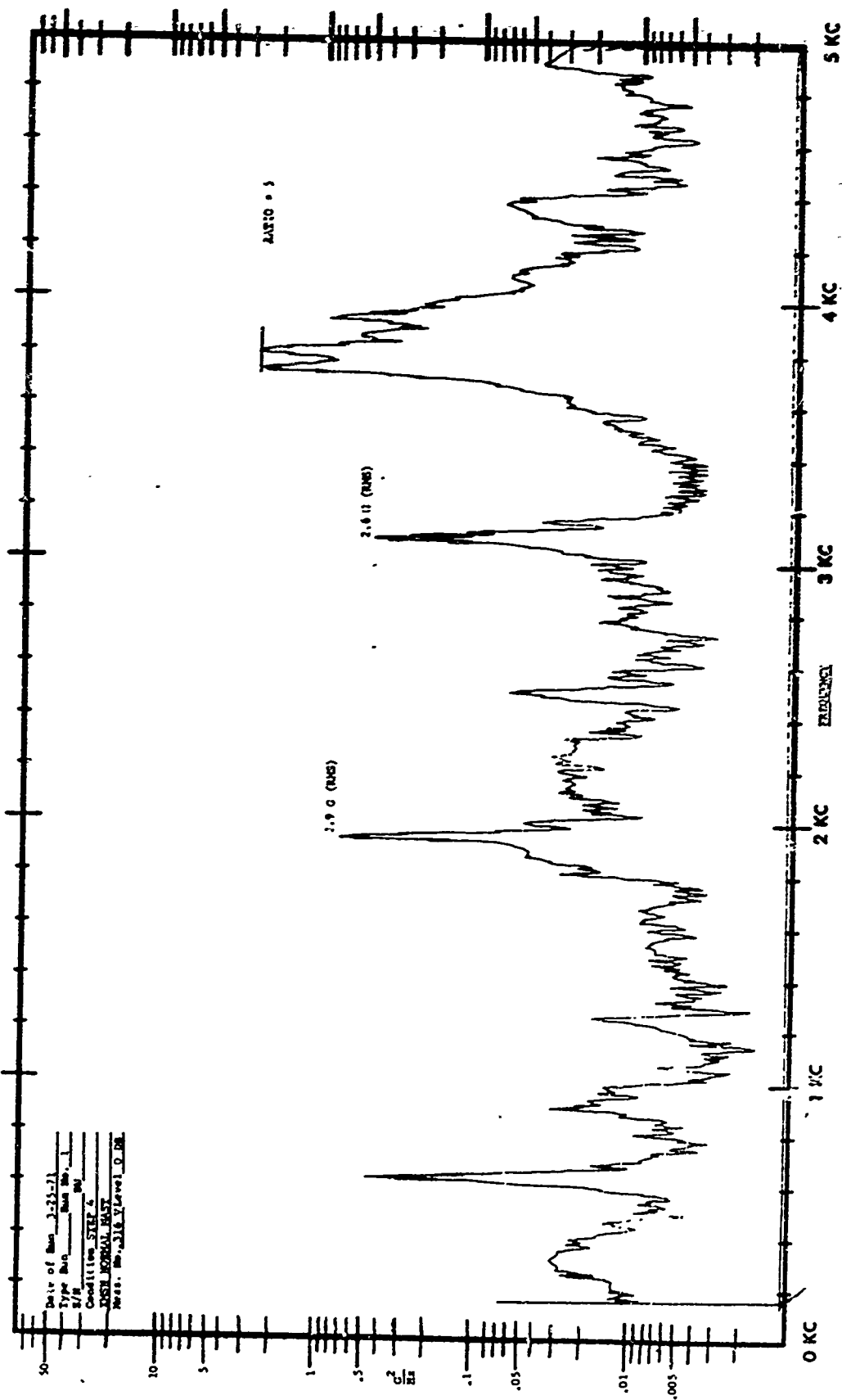


FIGURE 7-23 TRANSMISSION NORMAL MAST, 3/25/71, CLIMBING,  
DISCREPANT TAIL ROTOR OUTPUT QUILL BEARINGS

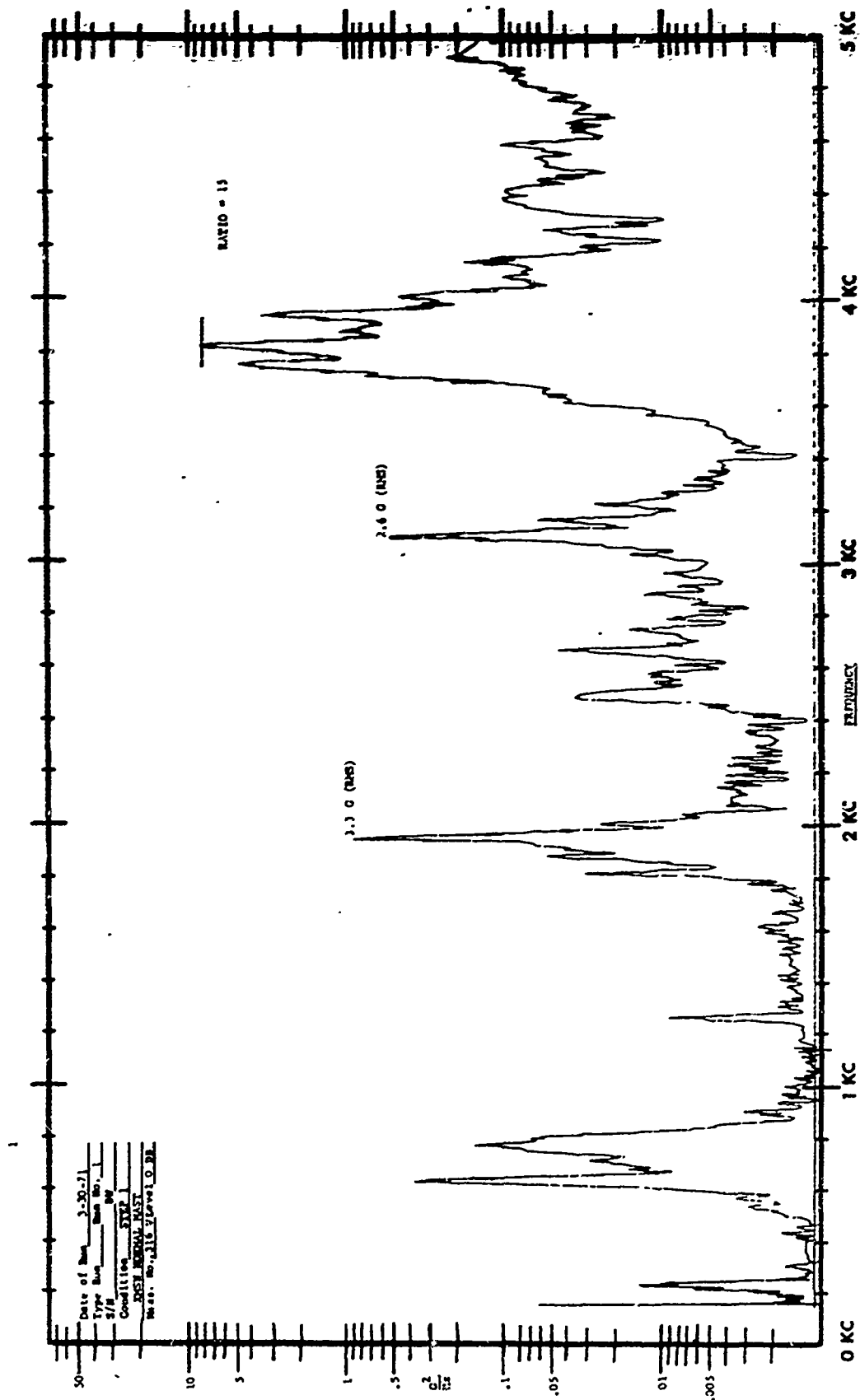


FIGURE 7-24 TRANSMISSION NORMAL MAST, 3/30/71,  
GROUND HOVER, DISCREPANT MAST BEARING

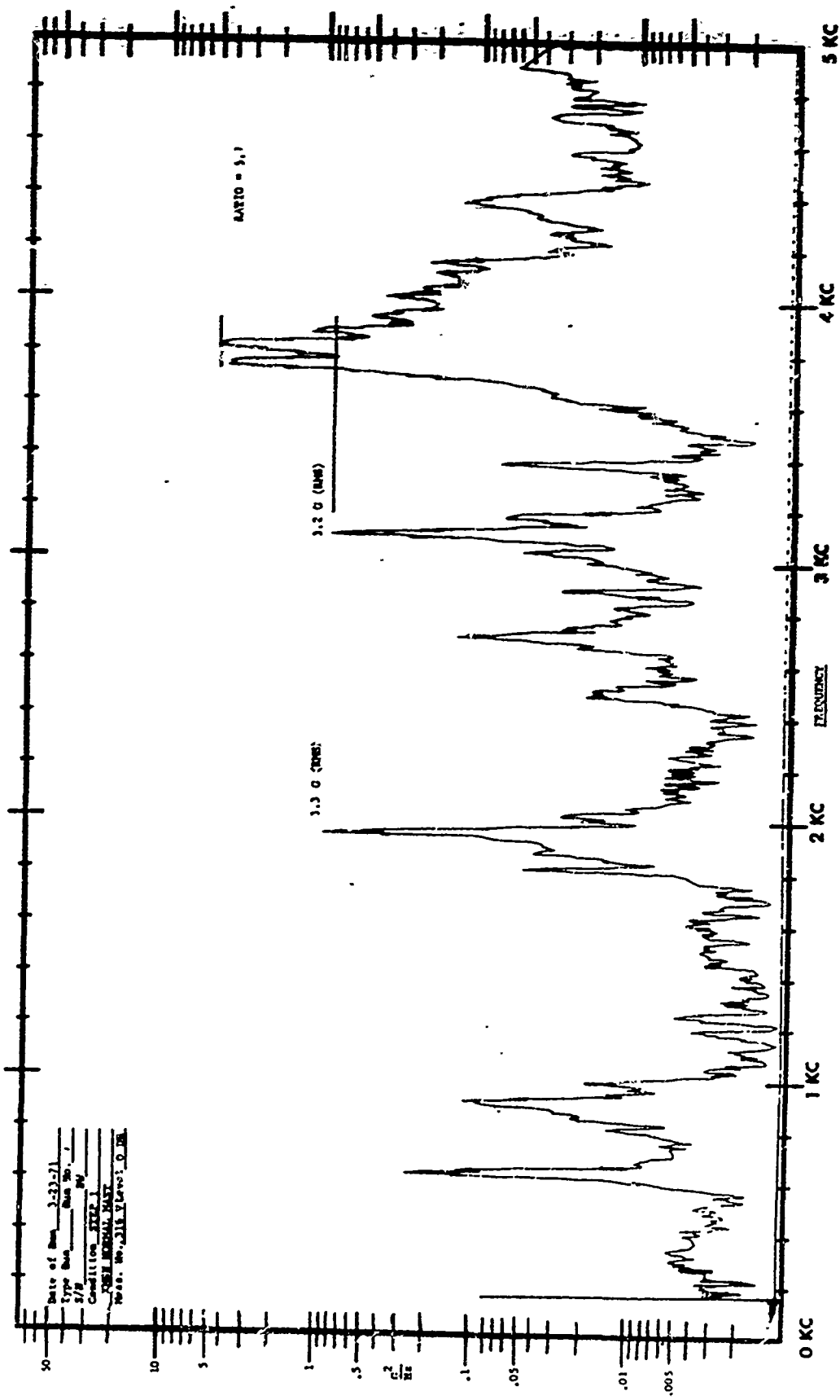


FIGURE 7-25 TRANSMISSION NORMAL MAST, 3/23/71, GROUND  
HOVER, DISCREPANT INPUT QUILL TRIPLEX BEARING

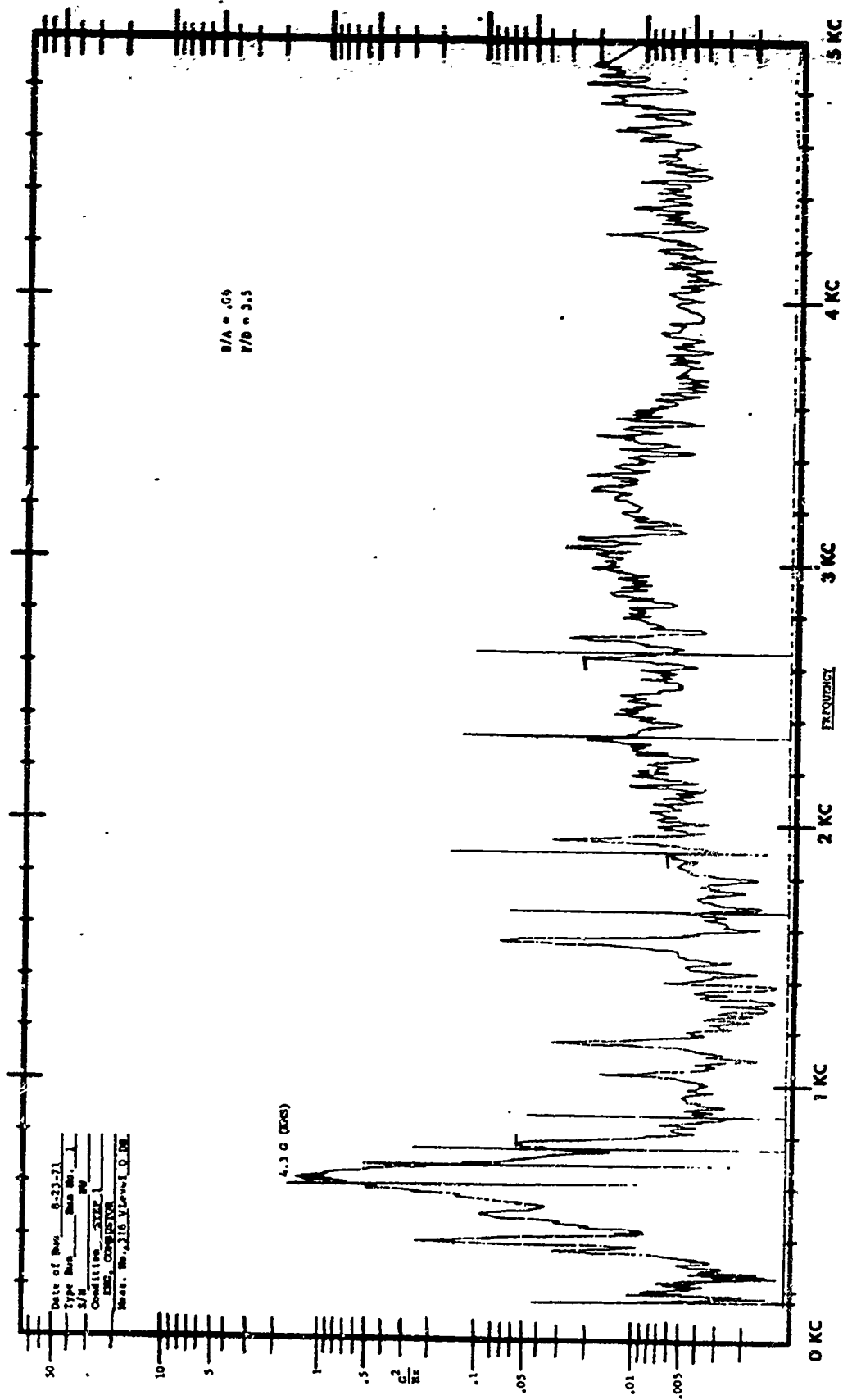


FIGURE 7-26 ENGINE COMBUSTOR, S/N 14819, 8/23/71,  
GROUND HOVER, NO DEFECTS

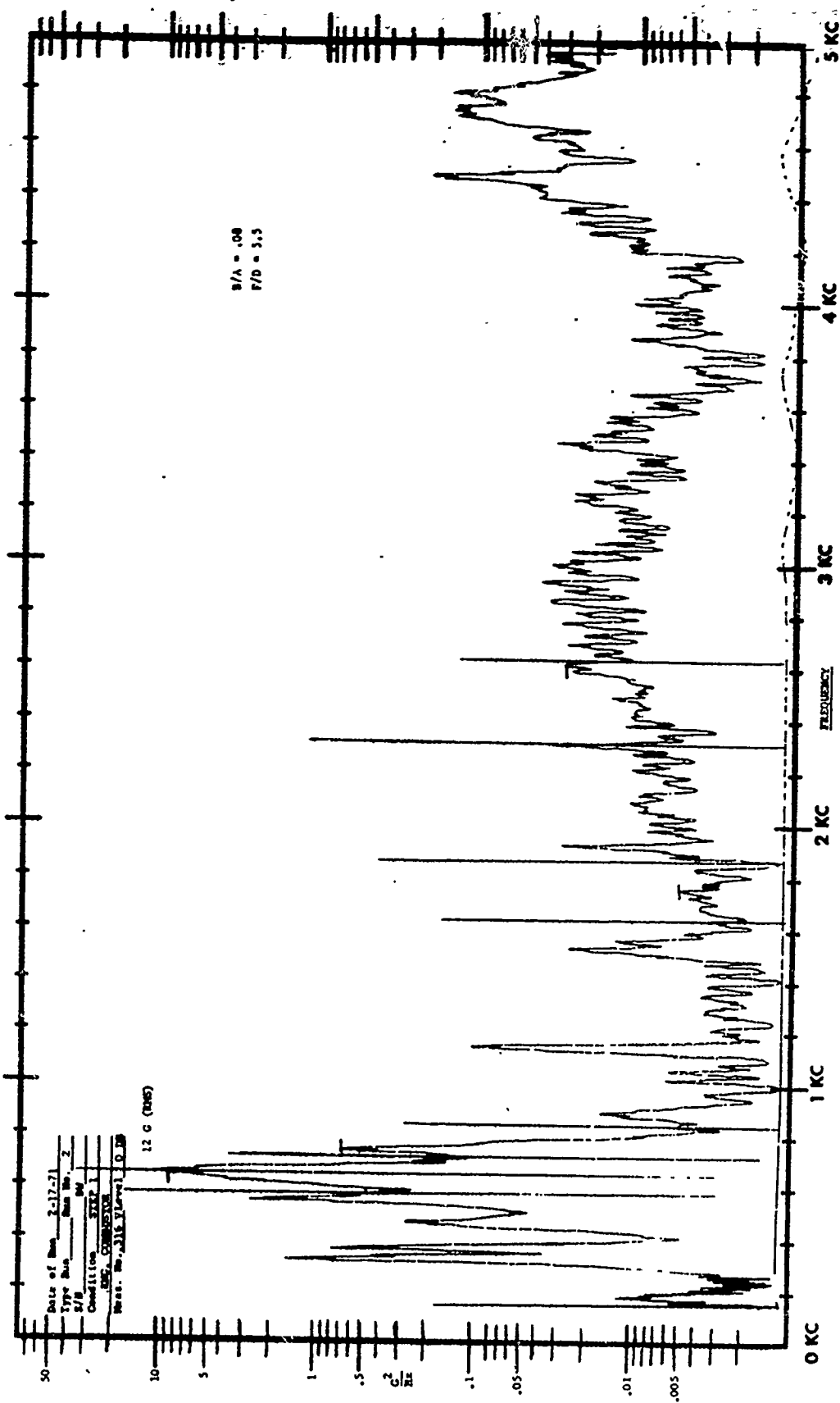


FIGURE 7-27 ENGINE COMBUSTOR, S/N 15615, 2/17/71,  
GROUND HOVER, DISCREPANT #2 BEARING

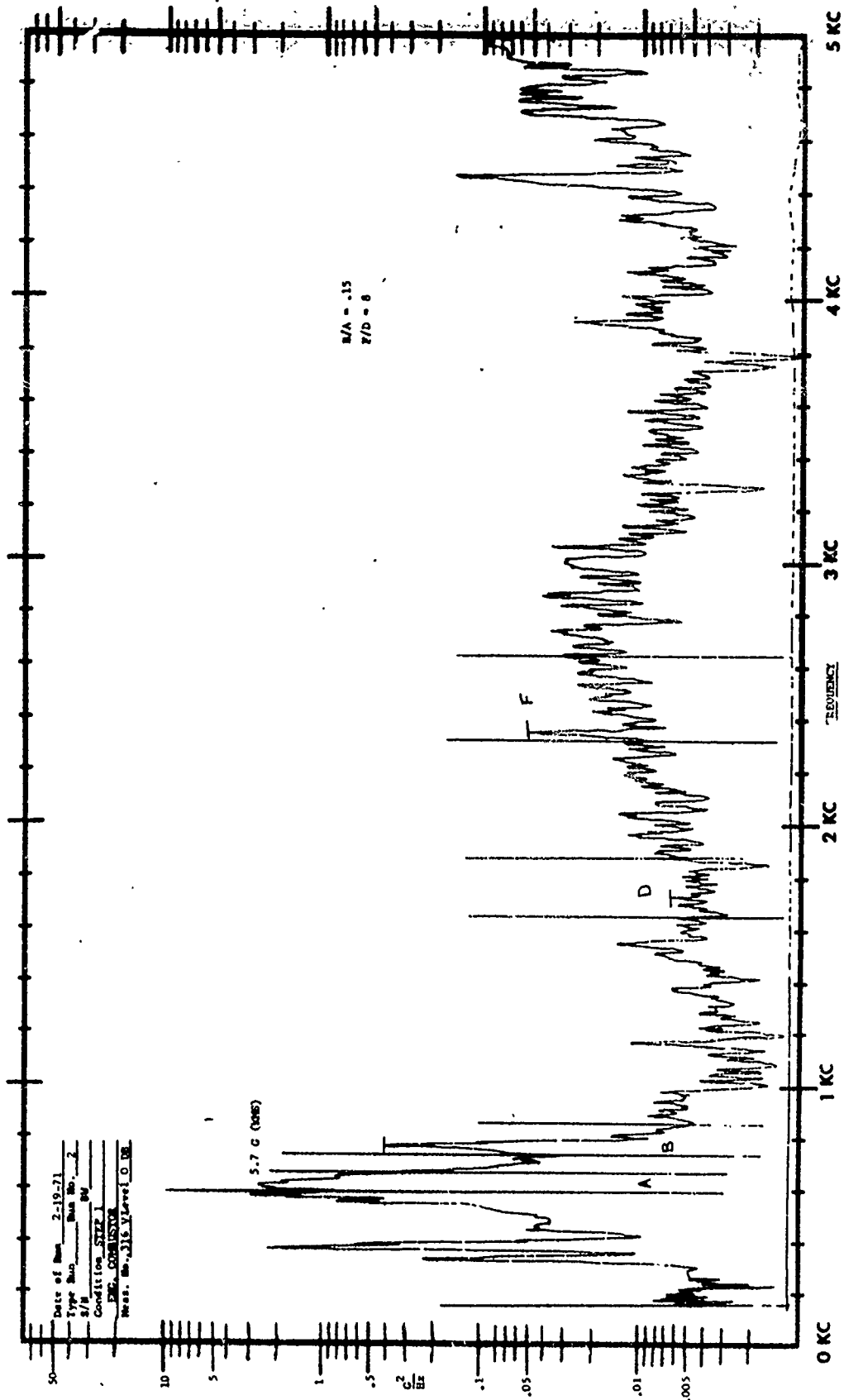
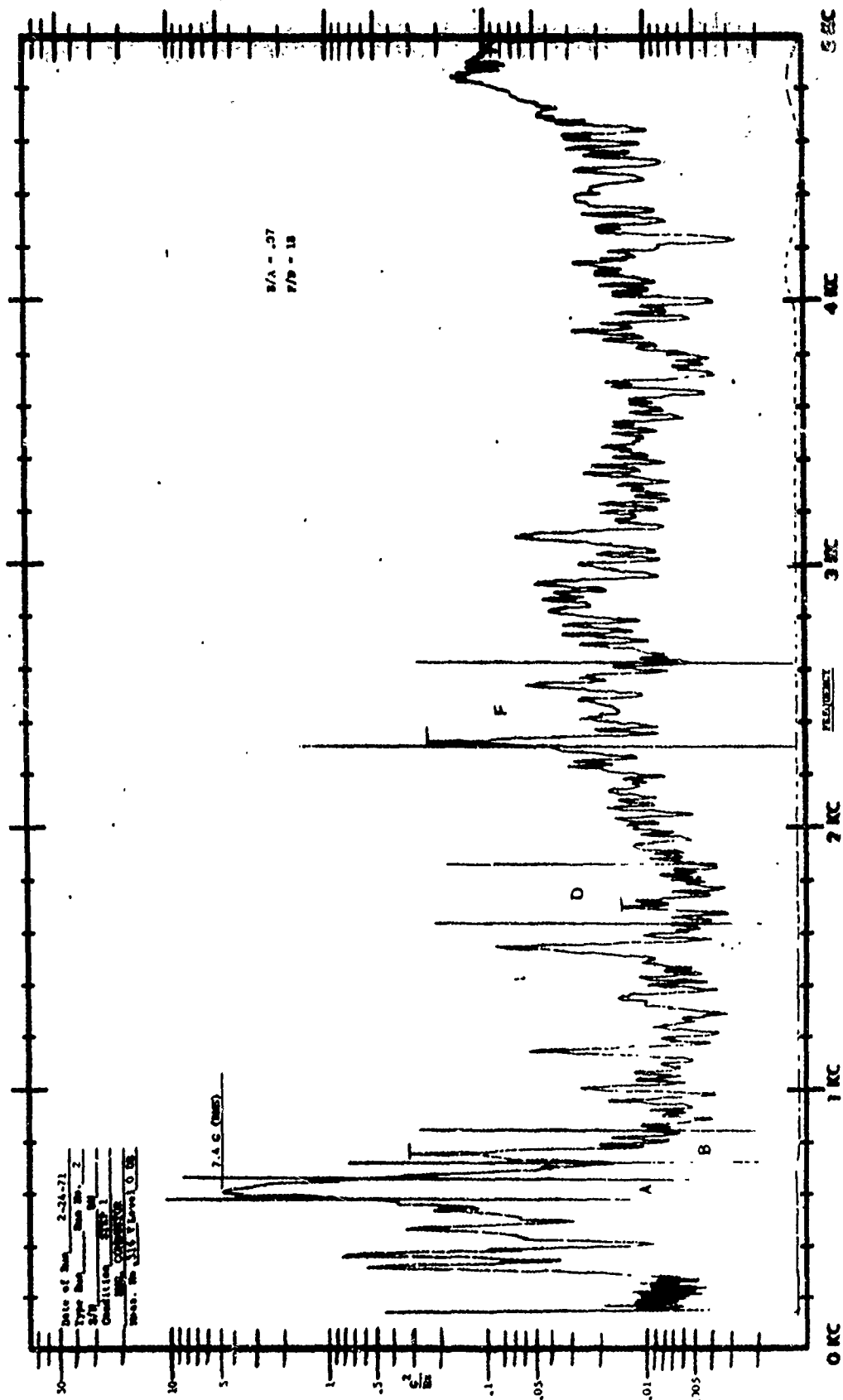


FIGURE 7-28 ENGINE COMBUSTOR, S/N 20727, 2/19/71,  
GROUND HOVER, DISCREPANT #3 BEARING



S/A = .07  
 F/B = 13

FIGURE 7-29 ENGINE COMBUSTOR, S/N 15351, 2/24/71,  
 GROUND HOVER, DISCREPANT #4 BEARING

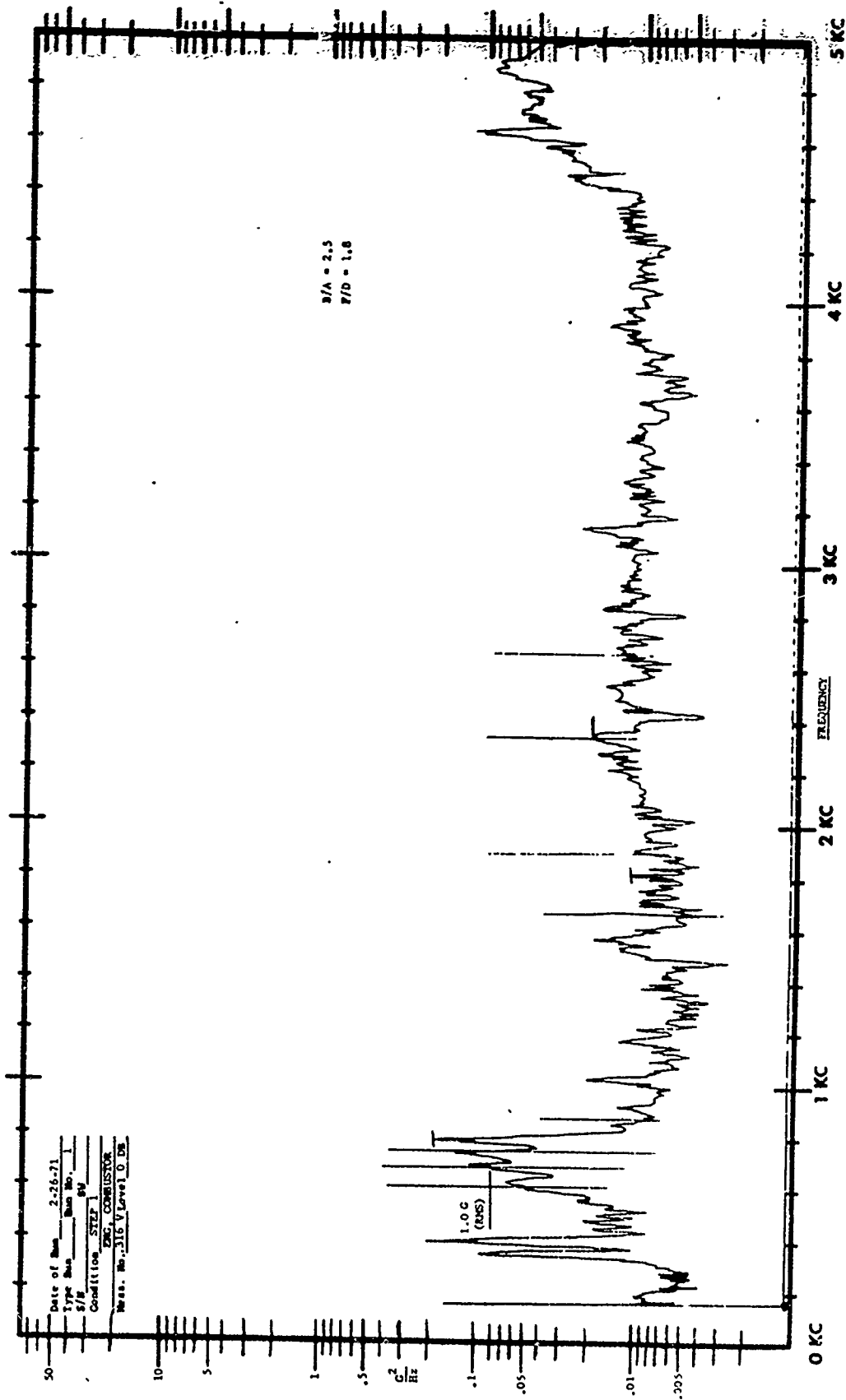


FIGURE 7-30 ENGINE COMBUSTOR, S/N 18993, 2/26/71,  
GROUND HOVER, DISCREPANT  $N_1$  NOZZLE

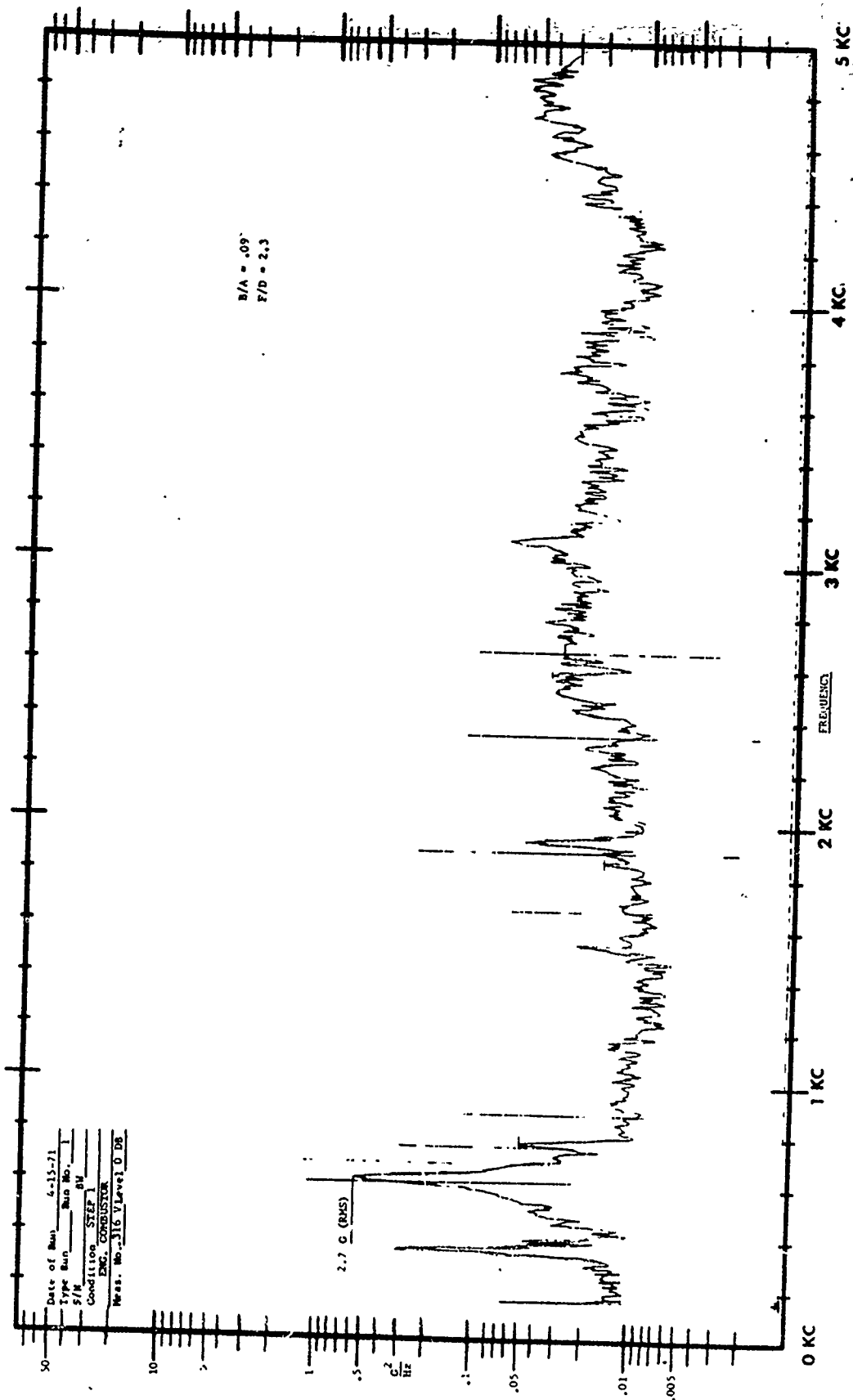


FIGURE 7-31 ENGINE COMBUSTOR, S/N 18993, 4/15/71,  
 GROUND HOVER, DISCREPANT  $N_2$  NOZZLE

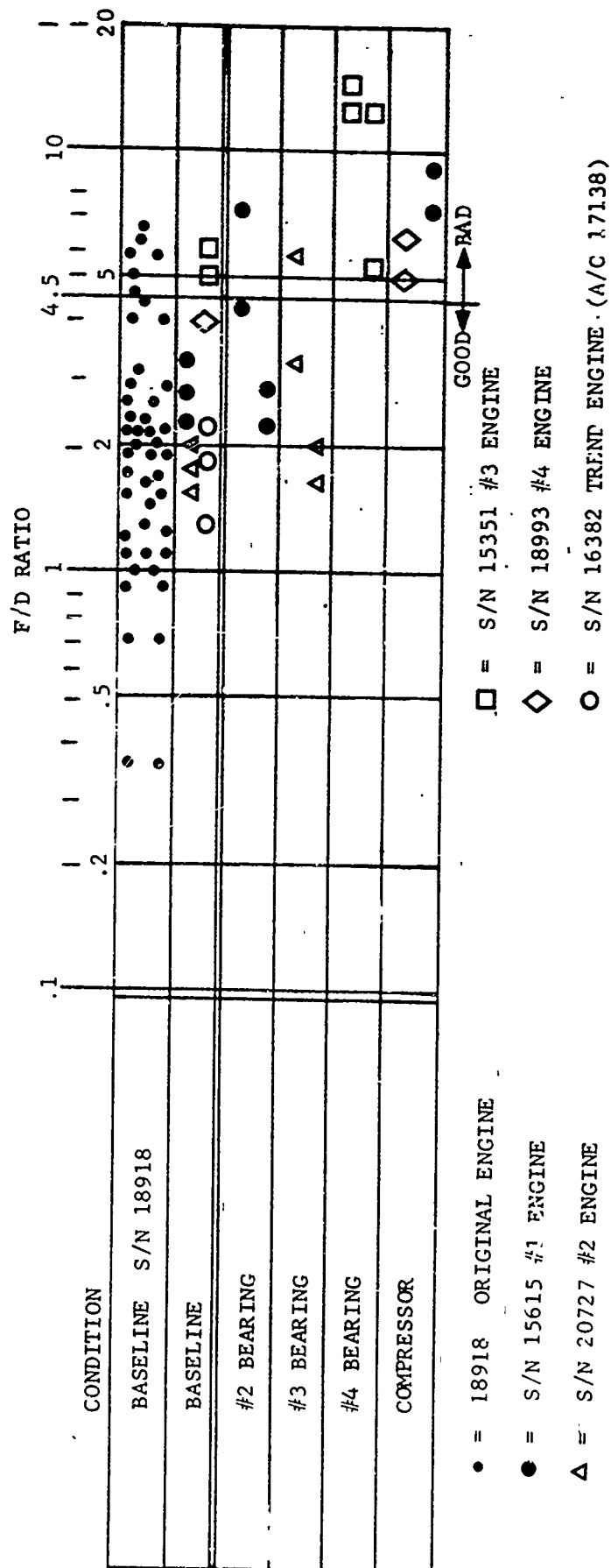
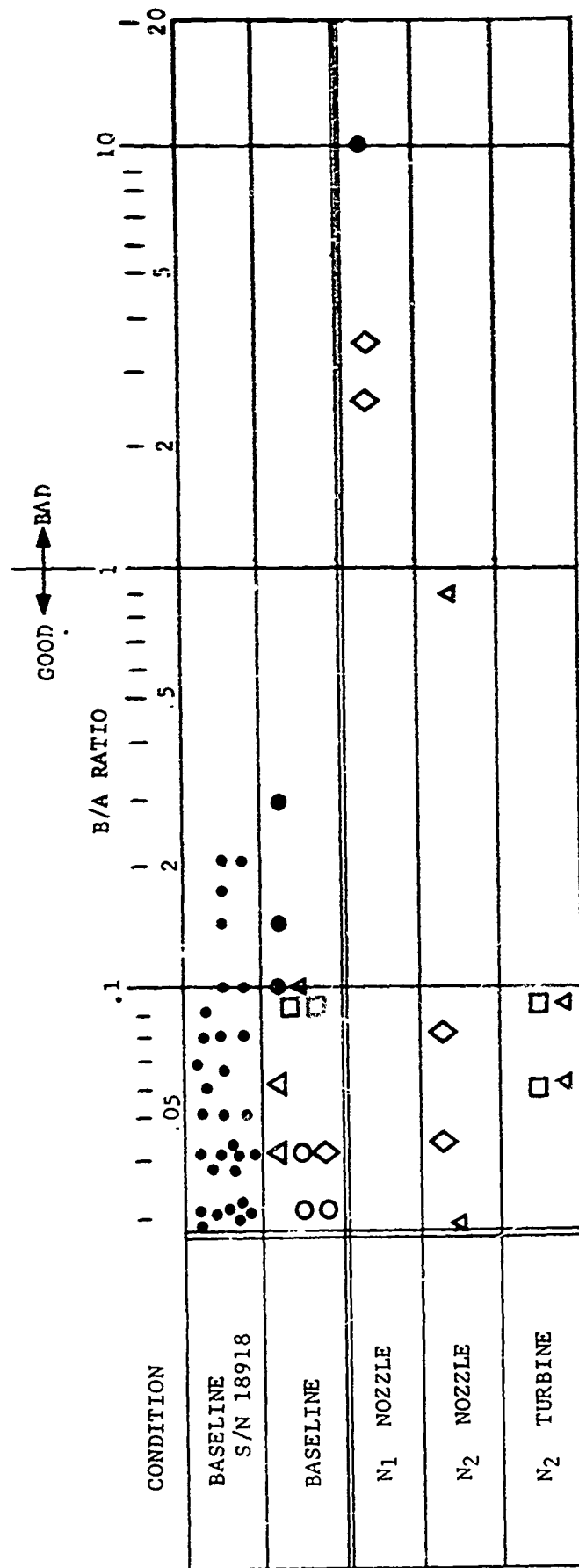


FIGURE 7-32 ENGINE COMBUSTOR F/D SUMMARY (GROUND HOVER)



- = S/N 18918 ORIGINAL ENGINE
- = S/N 15615 #1 ENGINE
- △ = S/N 20727 #2 ENGINE
- = S/N 15351 #3 ENGINE
- ◇ = S/N 18993 #4 ENGINE
- = S/N 16382 TREND ENGINE (A/C 1713R)

FIGURE 7-33 ENGINE COMBUSTOR B/A SUMMARY (GROUND HOVER)

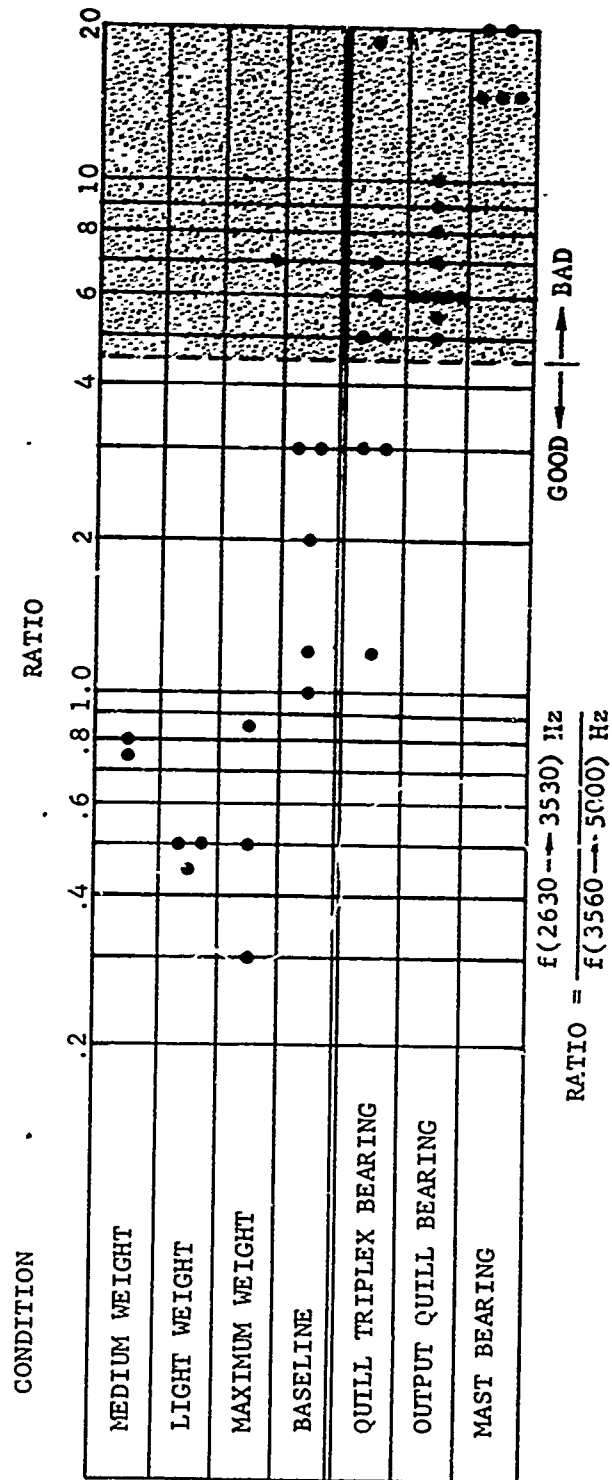


FIGURE 7-34 - TRANSMISSION (S/N A12-3159A) FLIGHT DATA

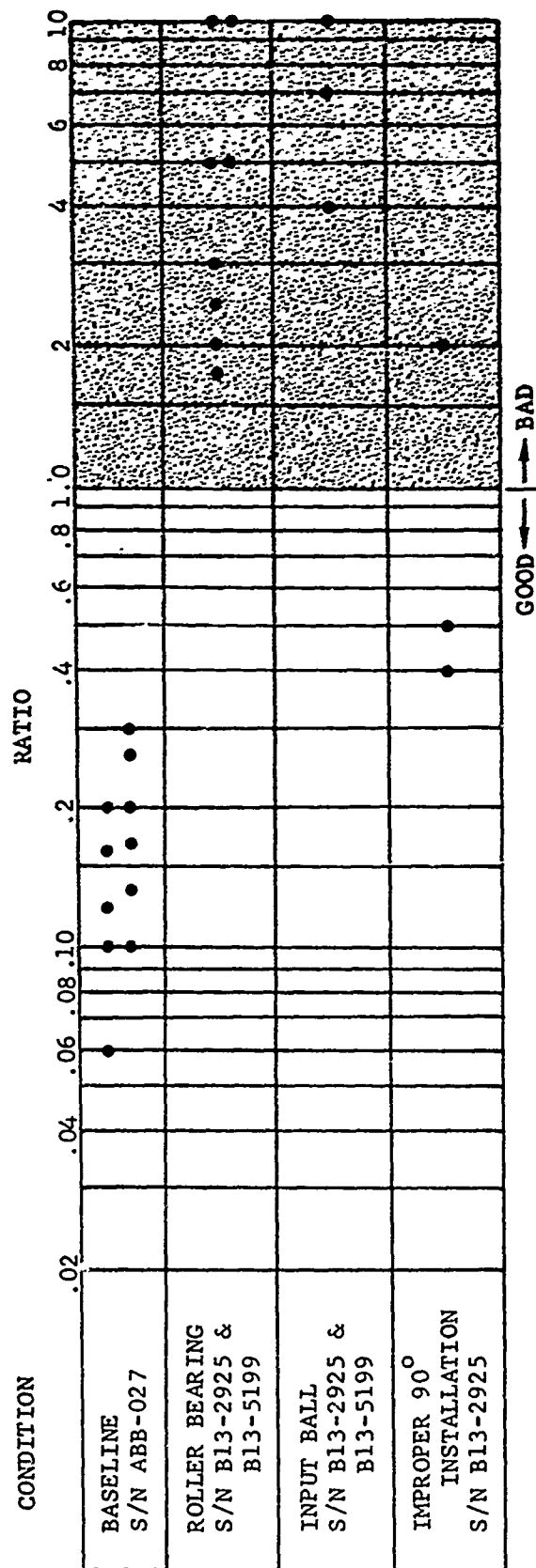


FIGURE 7-35 42° GEAR BOX FLIGHT DATA

(NOTE: SEE SECTION 7.9.8 FOR A SUMMARY OF NEW 42° GEARBOX CRITERIA)

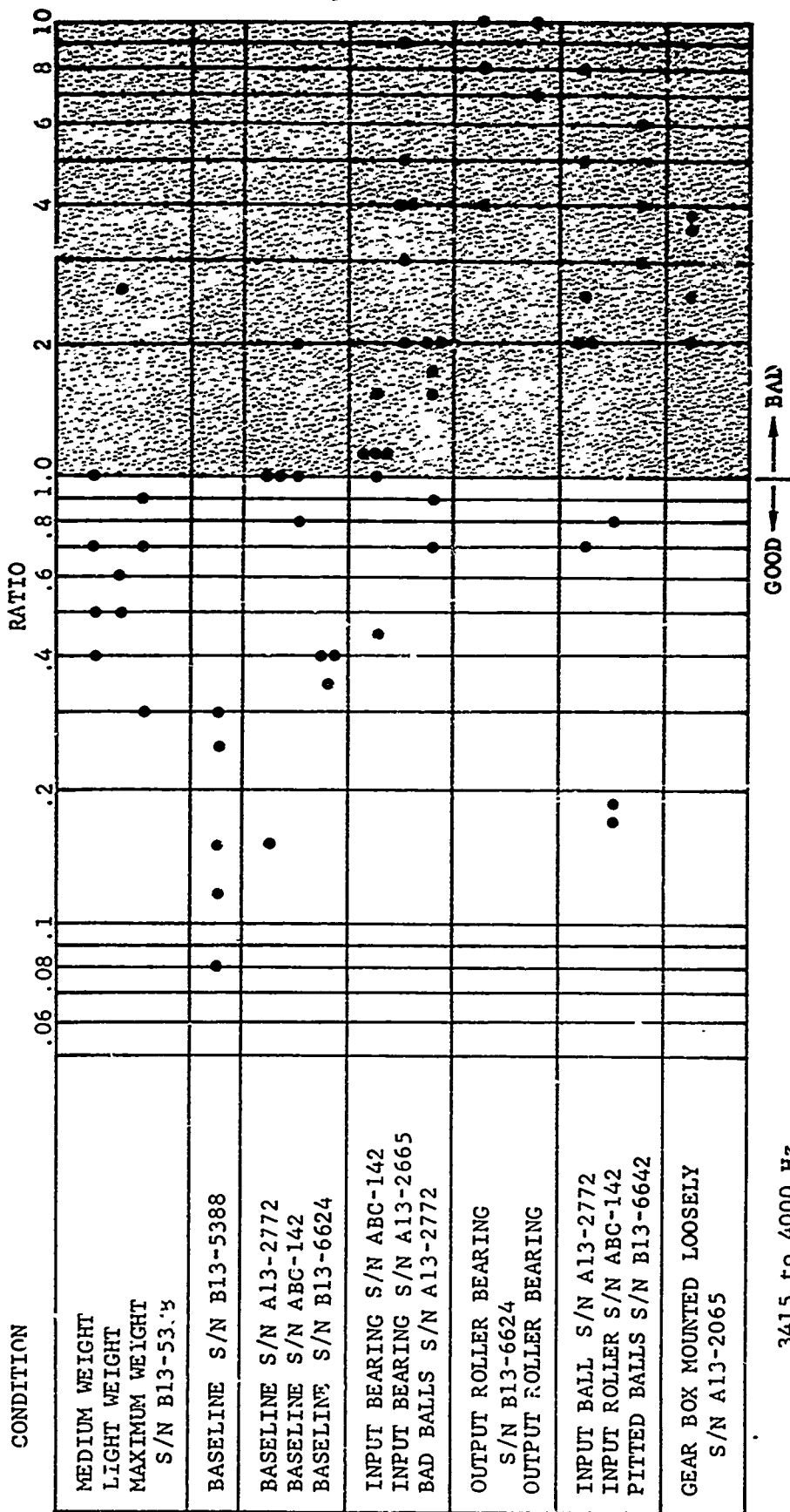


FIGURE 7-36 90° GEAR BOX FLIGHT DATA

RATIO =  $\frac{3415 \text{ to } 4000 \text{ Hz}}{4430 \text{ to } 5000 \text{ Hz}}$

it was discovered that a mix-up had occurred during calibration of accelerometers and the lateral and longitudinal connections had been reversed. The baseline flights, therefore, had no longitudinal data (lateral had shown no correlation early in the program and was not recorded). The criteria established, and subsequently used in verification tests, had only the data from the original gearbox of A/C 17448. (As a result of discrepant baselines flown during verification, the criteria had to be readjusted. See Section 7.9.)

Engine F/D ratio of 4.5 was implemented in the VSA to detect difference between good and bad. This value lies within the transition region and was chosen so that even marginal problems would cause the VSA to output a maintenance code. Data points above 4.0 on Baseline 18918 occurred after the engine had been reinstalled after a period of storage (while discrepant parts were being run). This step-like increase in ratios is attributed to mounting peculiarities.

## 7.7.2 ENGINE CALCULATOR AND GAS FLOW ANALYSIS CALCULATORS

### 7.7.2.1 Engine Calculators

Performance of the engine calculators during flight test proved the validity of the monitoring approach. This result is evident even though actual engines performed somewhat differently than the specification engines upon which the calculator design is based.

Evaluation of engine calculator data from the baseline and early discrepant flight tests indicated that response to abnormal conditions was less than anticipated. The results were similar to those of the test cell, which had only three data points per engine, and confirmed a need for greater sensitivity in the calculator. An analysis of methods of implementing sensitivity changes indicated that an optimum mechanization required significant change to existing hardware. A limited modification was made to the hardware during April, to amplify changes in the output of the engine calculator. This change also increased the magnitude of other changes such as the least significant bit (LSB) changes which occur in the digital circuits of the engine calculator. This effect made small changes in engine performance slightly more difficult to perceive even though detection of "abnormal" performance resulting from the implant of discrepant parts was much easier to detect.

Analysis of data acquired after the change showed that the calculator performance as a function of  $N_1$  was not a constant output. A negative rather than a zero slope is evident (see figure 7-37) and, as a result, essentially forced detection of "abnormal" conditions to the higher power ( $N_1$ ) levels. The net effect made the band of baseline data wider than really exists.

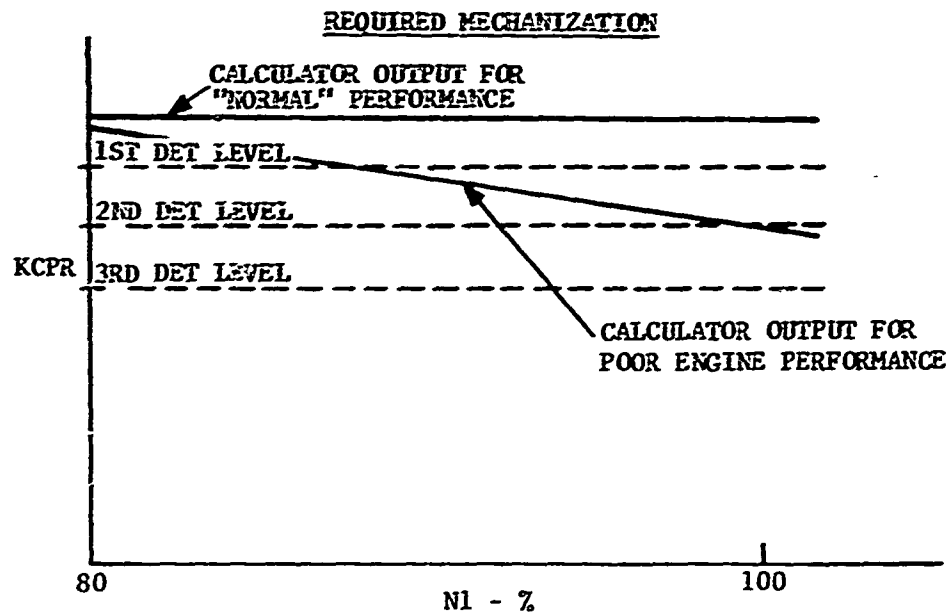
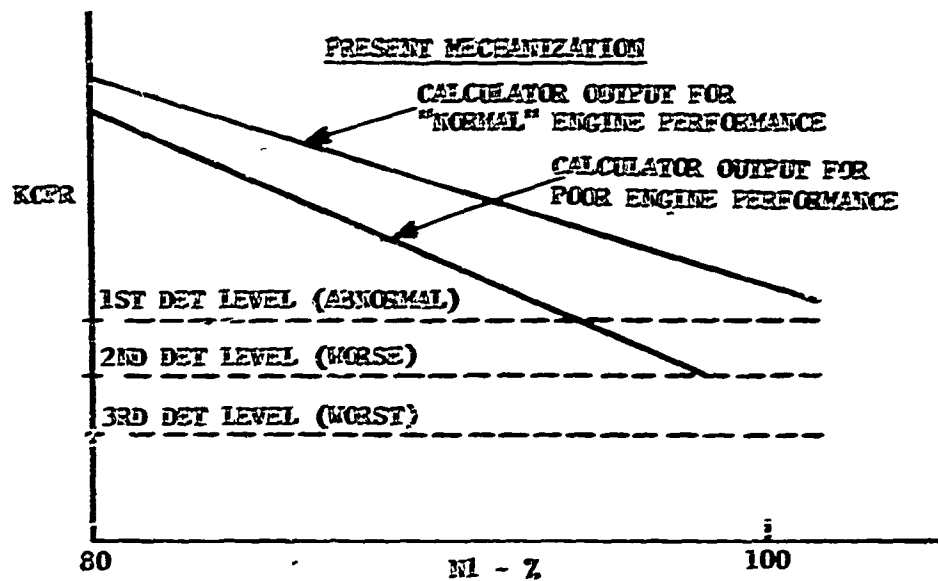


FIGURE 7-37 CALCULATOR SLOPE

Unfortunately, the opportunity of the MRS engine calculator to directly detect abnormal conditions after the changes were incorporated was limited to the remaining flight tests. As a result, increased emphasis was placed upon analysis of engine performance. Data normally acquired for checking calculator operation was used for the analysis and comparative plots of engine performance are used to evaluate performance, as well as to predict anticipated performance of an upgraded engine calculator.

Correlation of calculator operation to engine performance analysis is exemplified by data from a badly damaged (FOD) compressor flown on 10 June. Figure 7-36 shows the FOD compressor pressure ratio calculator (KCPR) output compared to baseline. As indicated in figure 7-38, the output levels were sufficient for all three of the maintenance code levels mechanized in the MRS. Only the first two levels were output because stability criteria was not satisfied and the low KCPR occurred for only a brief time.

By applying amplification factors to the "prechange" data, analysis of another less severely damaged compressor flown on 11 March indicated that the first KCPR level would have been outputted.

Correlations were good but not as successful for bearings, nozzles, and power turbine discrepant parts because slight performance changes were less than the effect of amplified digital LSB changes. Gas flow analysis confirmed the difficulty of correlation because it only showed significant changes from normal performance in the case of  $N_2$  nozzles.

#### 7.7.2.2 Gas Flow Analysis

Data from approximately 55 flights formed the flight test data base. Using five T53-L-13 engines, Table 7.4 presented the engine model numbers, discrepant parts, and flight dates of this flight test effort. The same engine performance relationships evaluated during the test cell phase were also used for the discrepant parts flight tests. The following parameters were measured for the gas flow analysis so that the engine thermodynamic performance could be evaluated for the MRS engine monitoring application.

- Engine gas producer rotor speed ( $N_1$ )
- Power turbine speed ( $N_2$ )
- Exhaust gas temperature (EGT)
- Torque pressure (Q)
- Engine fuel flow (WF)

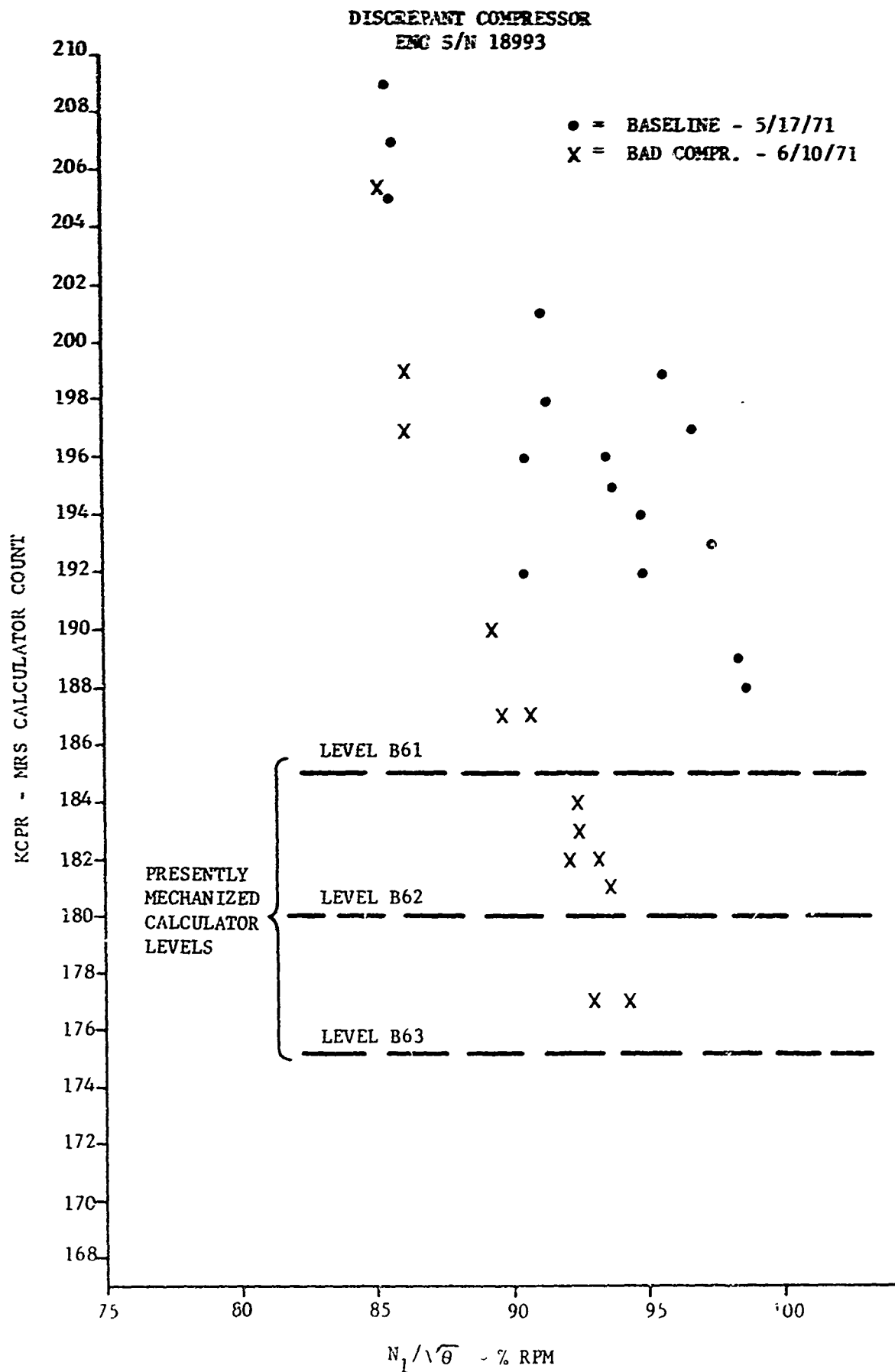


FIGURE 7-38 KCPT DISCREPANT COMPRESSOR ENG S/N 18993

- Compressor discharge pressure (CDP)
- Outside air temperature (OAT)
- Ambient pressure (Pam)

The equations used to convert the MRS engine output data counts to engineering units and to normalize the selected engine performance parameters for the engine inlet air conditions are presented in Table 7.9 (next page).

Engine performance characteristics were determined for the ten-step flight profiles discussed in paragraph 7.6.1. Table 7.10 shows the appropriate corrected engine speed for the ten-step profiles.

TABLE 7.10 CORRECTED ENGINE SPEED

<u>STEPS</u>	<u>FLIGHT CONDITION</u>	<u>CORRECTED ENGINE SPEED, %</u>
1	Ground Hover	92.60
2	500 Feet Altitude Cruise (Speed - 70 knots)	89.70
3	1,000 Feet Altitude Cruise (Speed - 115 knots)	94.00
4	Climb to 10,000 Feet Altitude	98.10
5	10,000 Feet Altitude Cruise (Speed - 80 knots)	91.20
6	10,000 Feet Altitude Cruise (Speed - Max. Safe Speed)	93.00
7	10,000 Feet Altitude Hover	95.30
8	Descent to 500 Feet Altitude	84.90
9	Landing	85.10
10	Flight Idle	68.50

Typical engine performance characteristics covering the ten-step flight profiles are shown in figures 7-39 through 7-46 for the engine S/N 14819 and 18993. Figures 7-39 through 7-41 present the comparison of the non-defective and discrepant compressor engine S/N 14819 performance data. The figures show that for the purpose of determining engine health condition, a corrected engine speed of greater than 90 percent is desirable from the engine performance considerations. Preferred engine speed for monitoring engine performance, with the inlet guide vanes completely open, is 92 to 95 percent depending on ambient temperature, because the engine performance values will be more

TABLE 7.9 PARAMETER PHYSICAL UNITS CONVERSION

NO.	PARAMETER	CONVERSION EQUATIONS		UNITS
		A/C 17448	A/C 17138	
1	Engine Speed	$N_1 = 36571. / (J4+256)$	$N1 = 36571. / (J4+256)$	Percent
2	Exhaust Gas Temperature	$EGT = 3.15J5+662$	$EGT = 3.15J5+662$	Degrees F
3	Torque	$Q = 0.753J+5.2$	$Q = 0.765J6+2.5$	Lbs/square inch
4	Power Turbine Speed	$N_2 = 35716 / (J7+256)$	$N_2 = 35716 / (J7+256)$	Percent
5	Ambient Pressure	$Pamb = 0.117J8+0.45$	$Pamb = 0.126J8-0.6$	Inches Hg
6	Compressor Discharge Pressure	$CDP = (0.4315J9+1.0)$	$CDP = (0.4275J9+1.8)$	Lbs/square inch
7	Outside Air Temperature	$-0.4912 \text{ Pamb}$	$-0.4912 \text{ Pamb}$	Degrees F
8	Fuel Flow Rate	$OAT = 0.828J10-62.5$ $WF = 0.00293J11$	$OAT = 0.8075J10-65$ $WF = 0.00293J11$	Gal/min
Normalized Parametric Equations:				
1	Compressor PressureRatio	$CPR = CDP / 0.4912 \text{ Pamb}$		Percent
2	Corrected Engine Speed	$N_1 / \theta = N1 / \sqrt{(OAT+460) / 519}$		Percent
3	Corrected Exhaust Gas Temperature	$EGT / \theta = \left\{ (EGT+460) / (OAT+460) / 519 \right\}$	-460	Degrees F
4	Corrected Fuel Flow	$WF / \delta \sqrt{\theta} = 386 \text{ WF} / \left[ (Pamb / 29.92) \left( \sqrt{(OAT+460) / 519} \right) \right]$		Lbs/hour
5	Corrected Shaft Horsepower	$SHP / \delta \sqrt{\theta} = 220.9 QN_2 / \left[ 960 (Pamb / 29.92) \left( \sqrt{(OAT+460) / 519} \right) \right]$		Horsepower

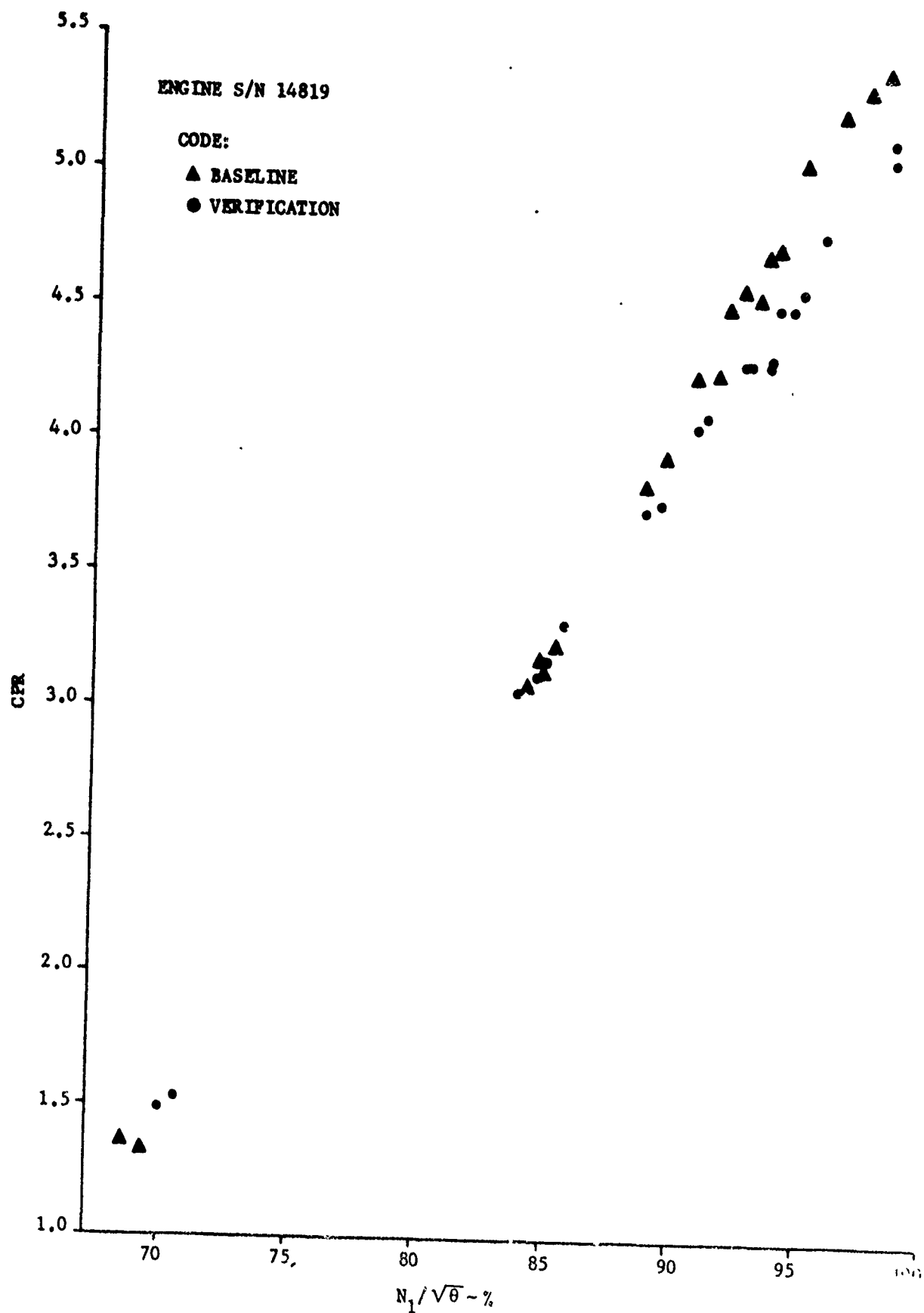


FIGURE 7-39 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

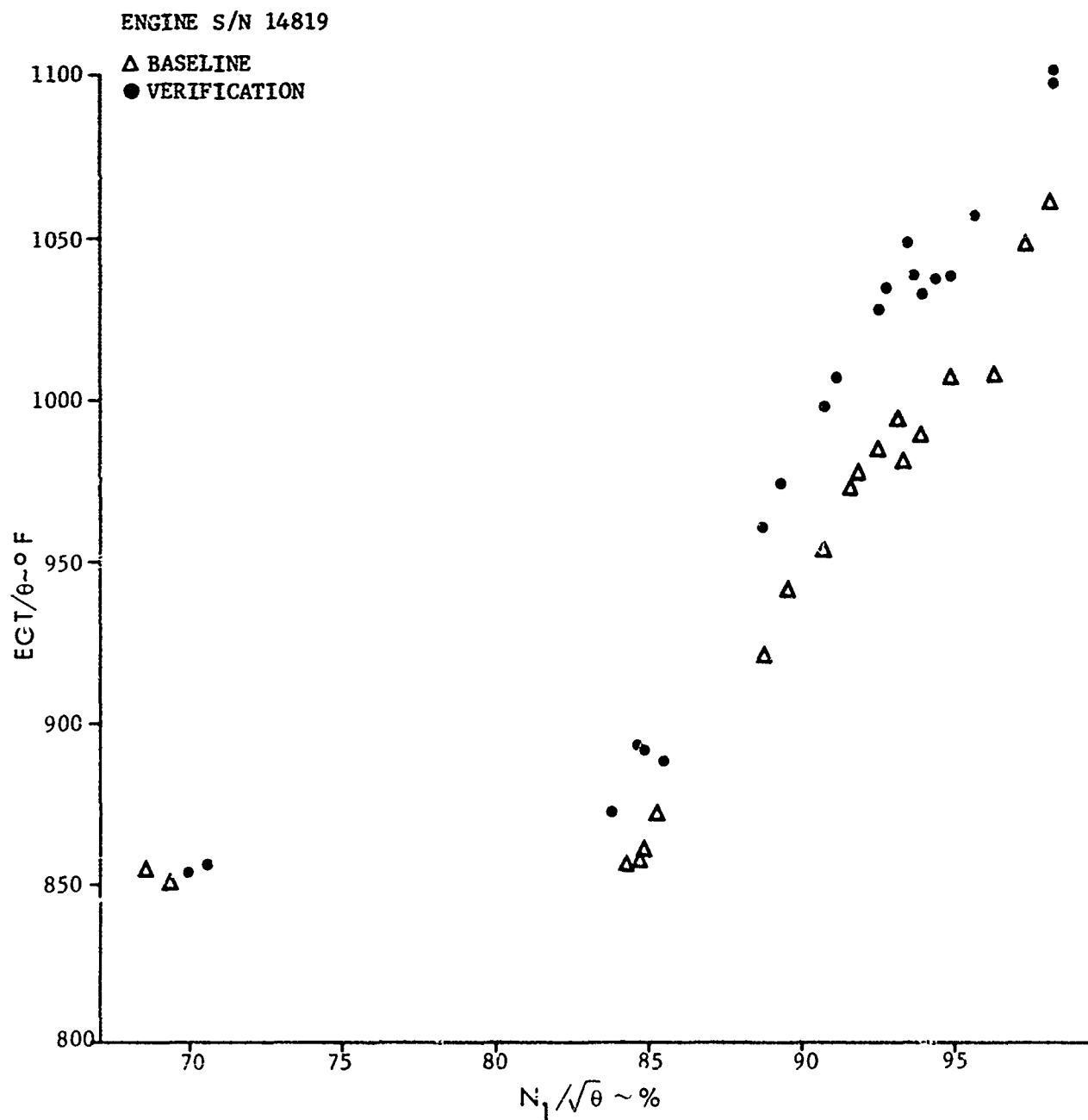


FIGURE 7-40 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

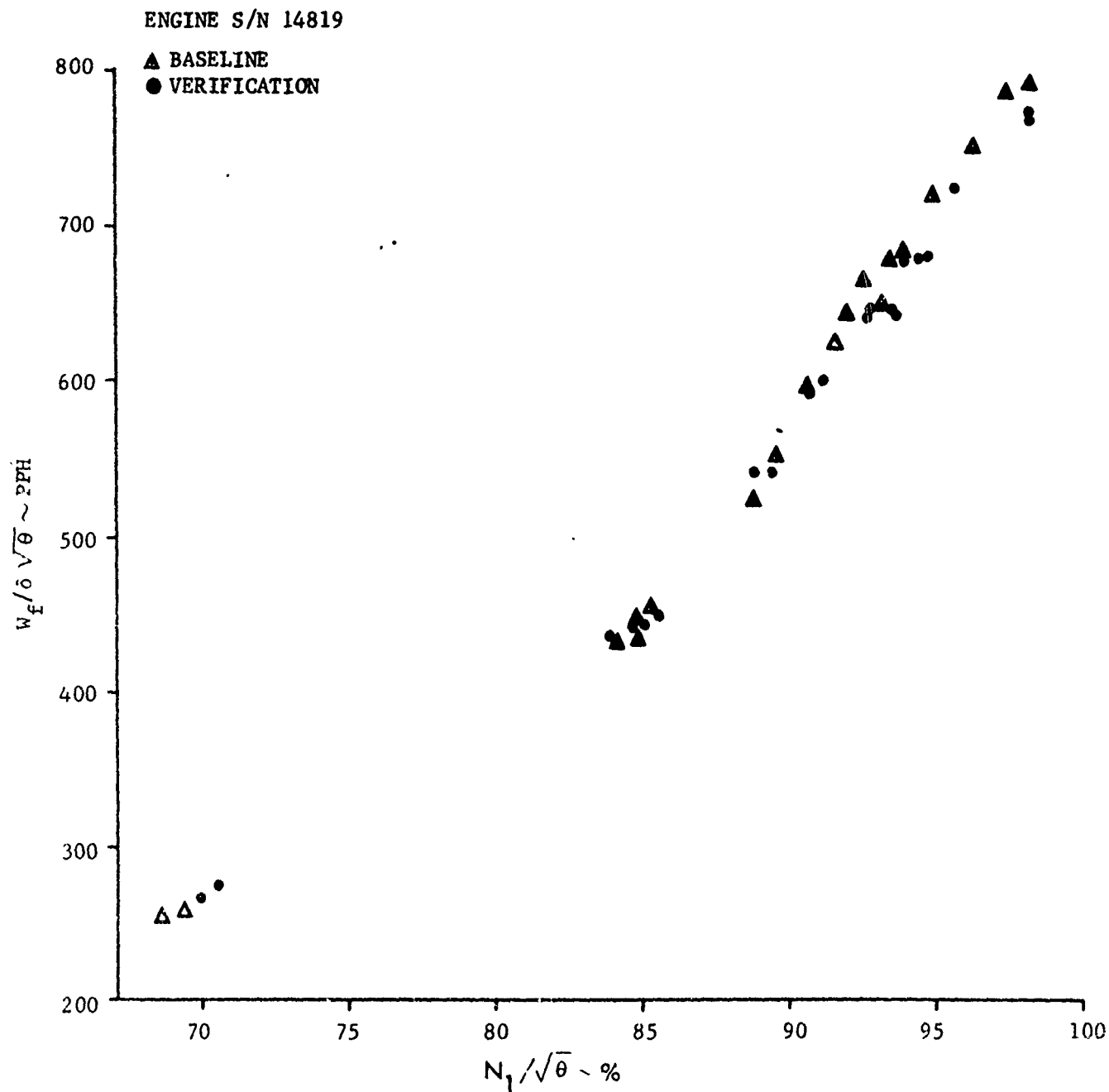


FIGURE 7-41 CORRECTED FUEL FLOW VS CORRECTED  $N_1$  SPEED

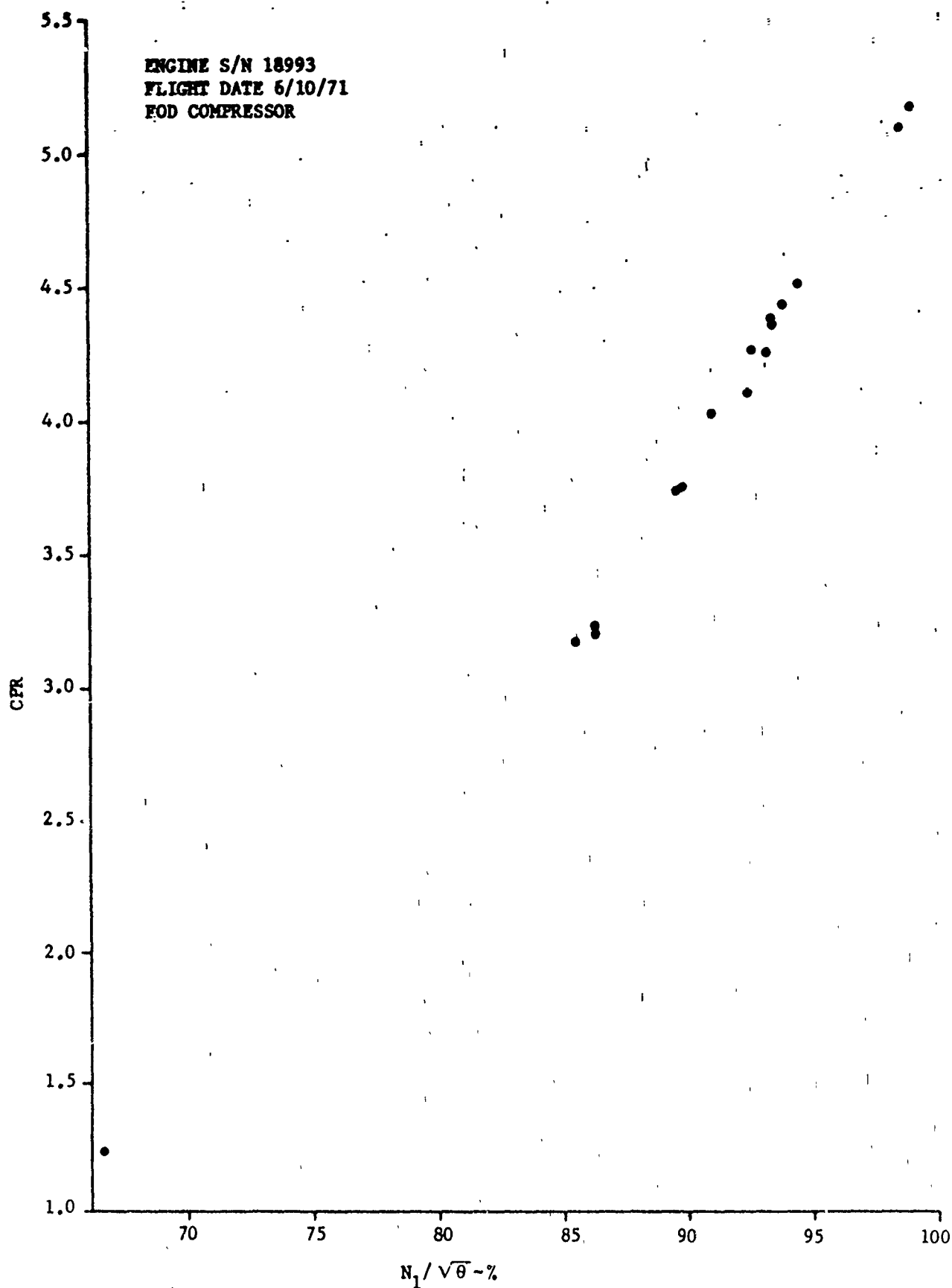


FIGURE 7-42 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

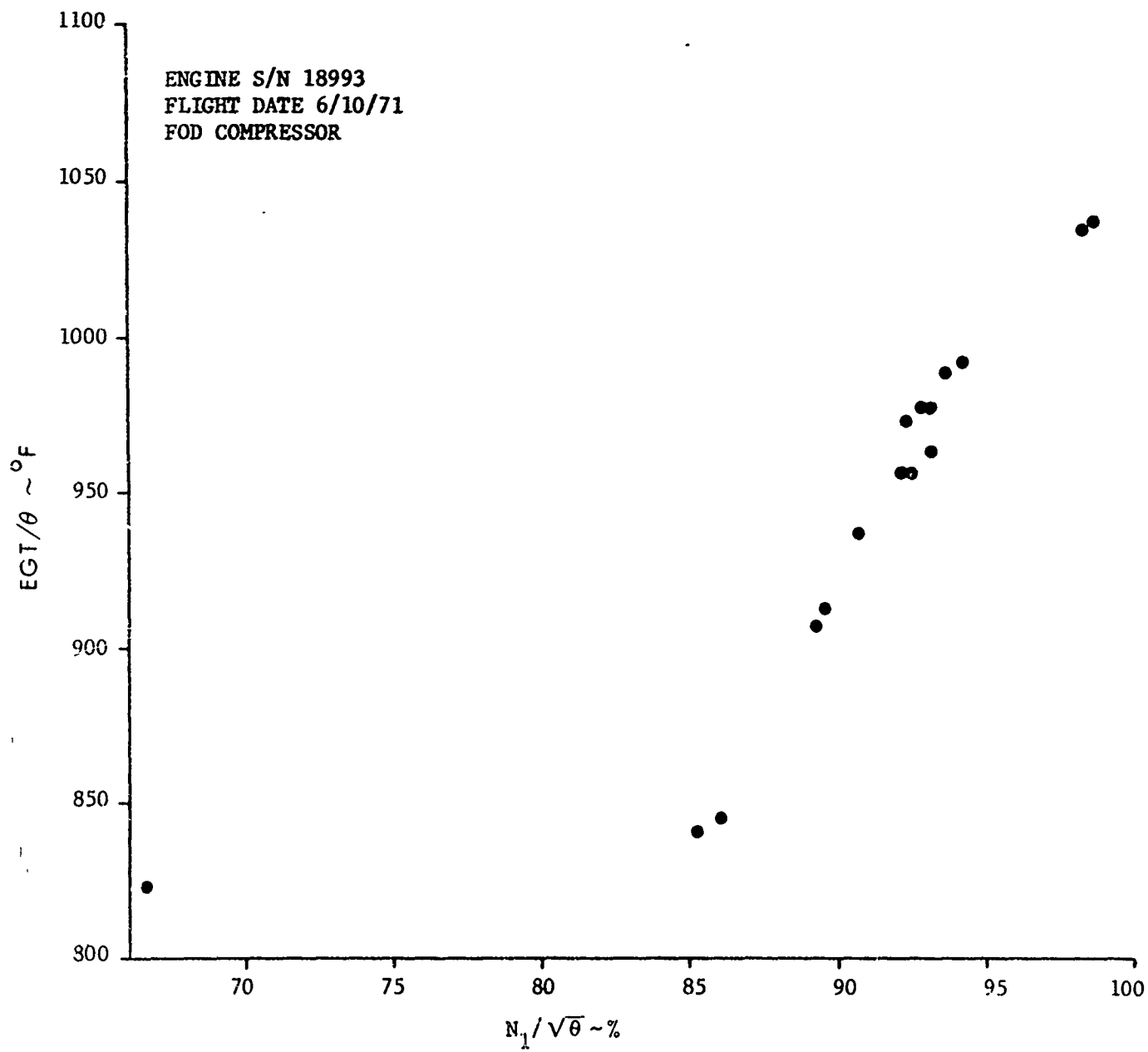


FIGURE 7-43 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

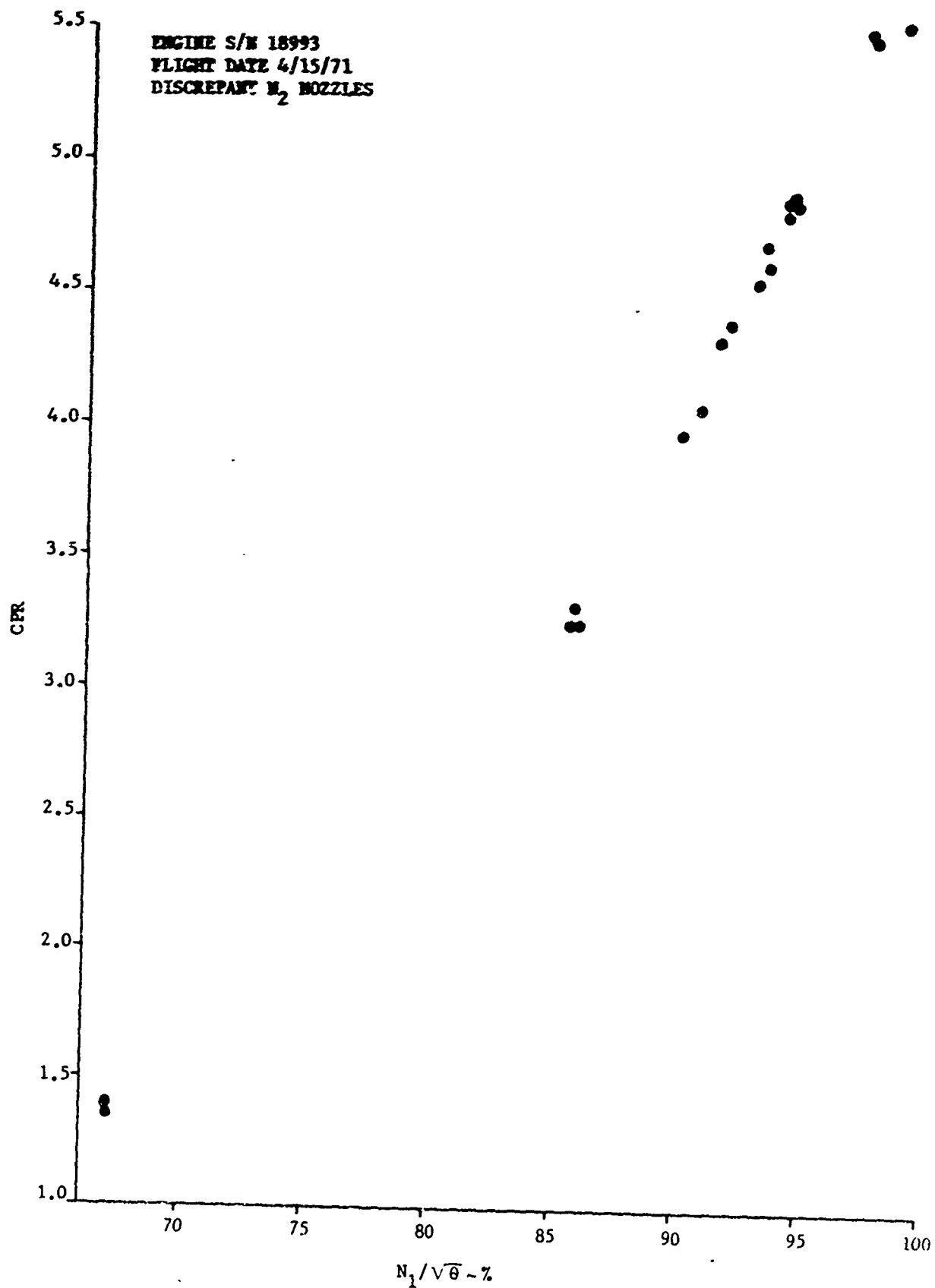


FIGURE 7-44 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

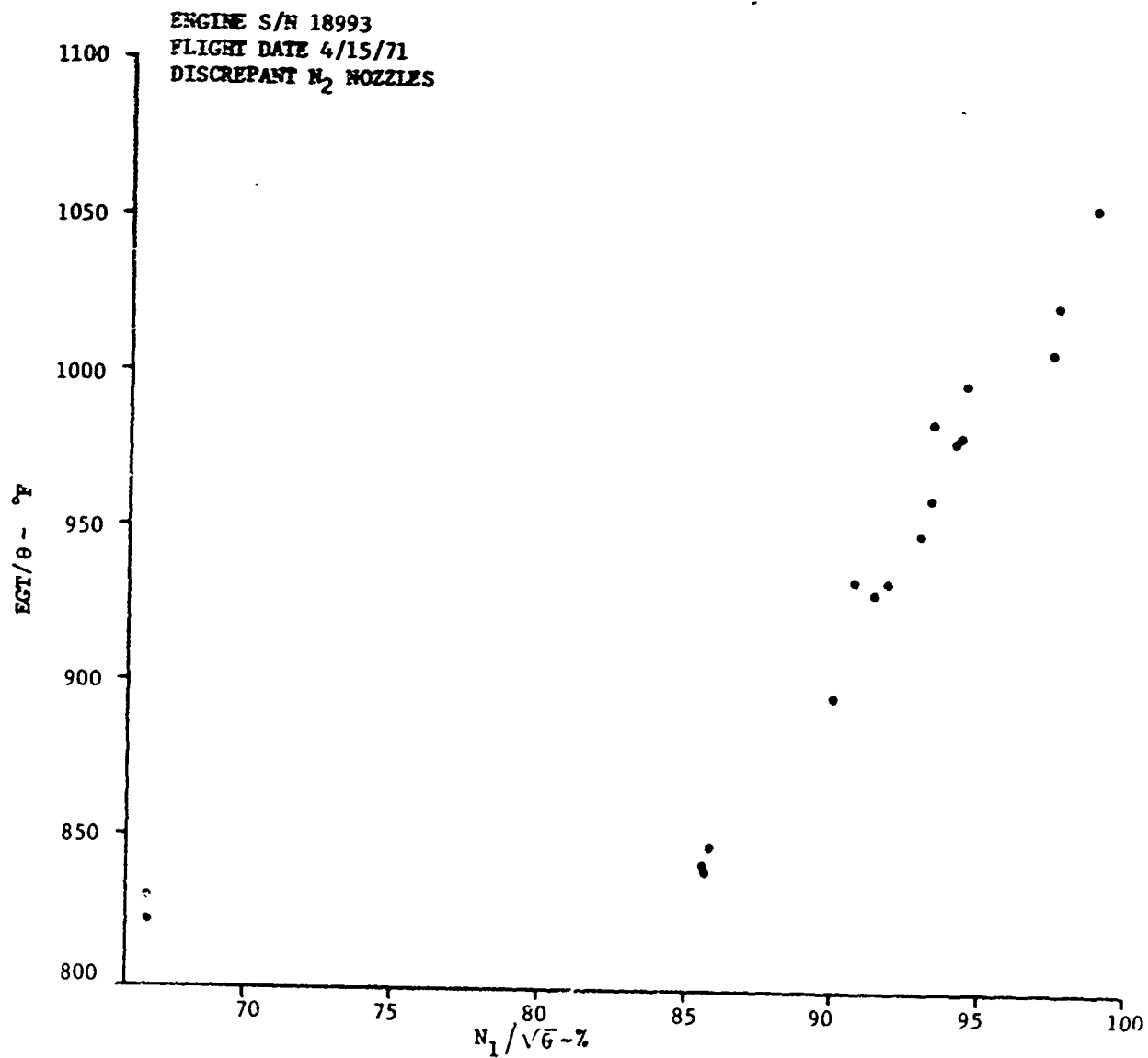


FIGURE 7-45 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

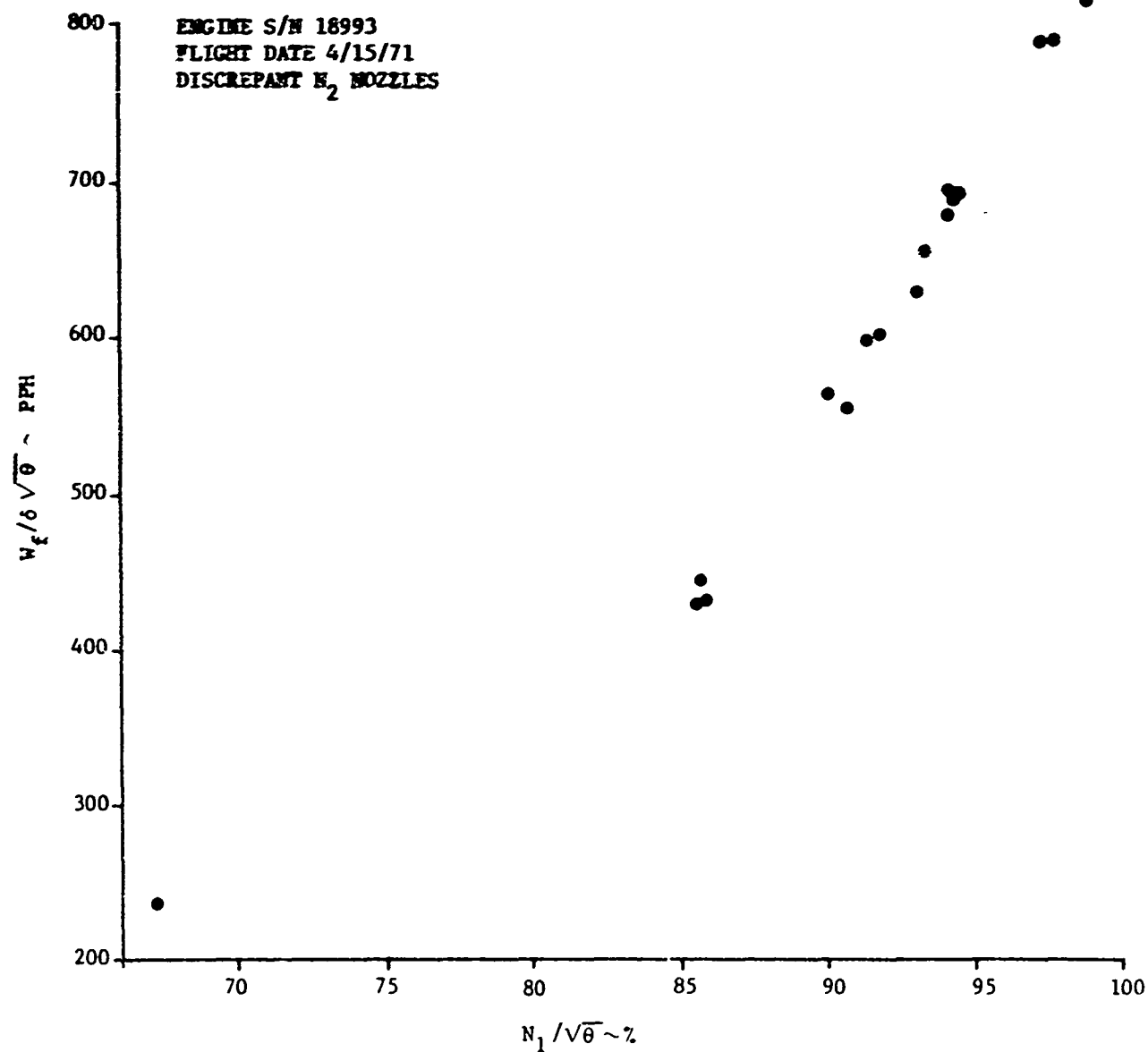


FIGURE 7-46 CORRECTED FUEL FLOW VS CORRECTED  $N_1$  SPEED

consistent and follow the performance relationship implemented in the engine calculator. Also, the performance deviation for discrepant engine is more pronounced at high engine speed. Flight idle conditions, step 10, provides the least performance information because of the following:

- a) Non-linearity of engine performance parameter relationships; therefore, not applicable for calculator use.
- b) Difficult to determine performance deviations and performance parameters at low values.
- c) Interstage air bleed operation could produce inconsistent performance data.

Based on the above considerations, the step 10 flight mode was not used to diagnose engine status during discrepant part and verification flight test phases.

The engine-to-engine performance variations for the five non-defective engines are shown in figures 7-47 through 7-51. These figures show significant performance spreads between engines occur on two parameters -- exhaust gas temperature and shaft horsepower. The scatter on compressor pressure ratio data is moderate. Unfortunately, the engine fuel flow was not recorded on three engine flight tests. Therefore, figure 7-50 shows the engine fuel flow data for the two engines. These performance engines of the averaged value or the band of distribution is used for common baseline. In order to effectively monitor engine performance, the individual engine signature was used to evaluate the effect of discrepant parts on a specific engine rather than the averaged values.

The effects of discrepant main shaft (No. 3) bearings, power turbine ( $N_2$ ) nozzles, and power turbine on engine S/N 20727 performance are presented in figures 7-52 through 7-63. Baseline engine performance data was determined from the flight conducted on 3 May. The results of the gas flow analysis revealed the following:

- a) Both flight tests (19 February 1971 and 3 June 1971) conducted with discrepant No. 3 bearings implanted showed no performance change from baseline values (see figures 7-52 through 7-57). The selected discrepant bearing specimens

# NONDISCREPANT ENGINES

CODE:

- = ENG S/N 18918 FLT-6/28/71
- = ENG S/N 20727 FLT-5/3/71
- ▲ = ENG S/N 15351 FLT-5/24/71
- = ENG S/N 15615 FLT-5/12/71
- ◆ = ENG S/N 18993 FLT-5/17/71

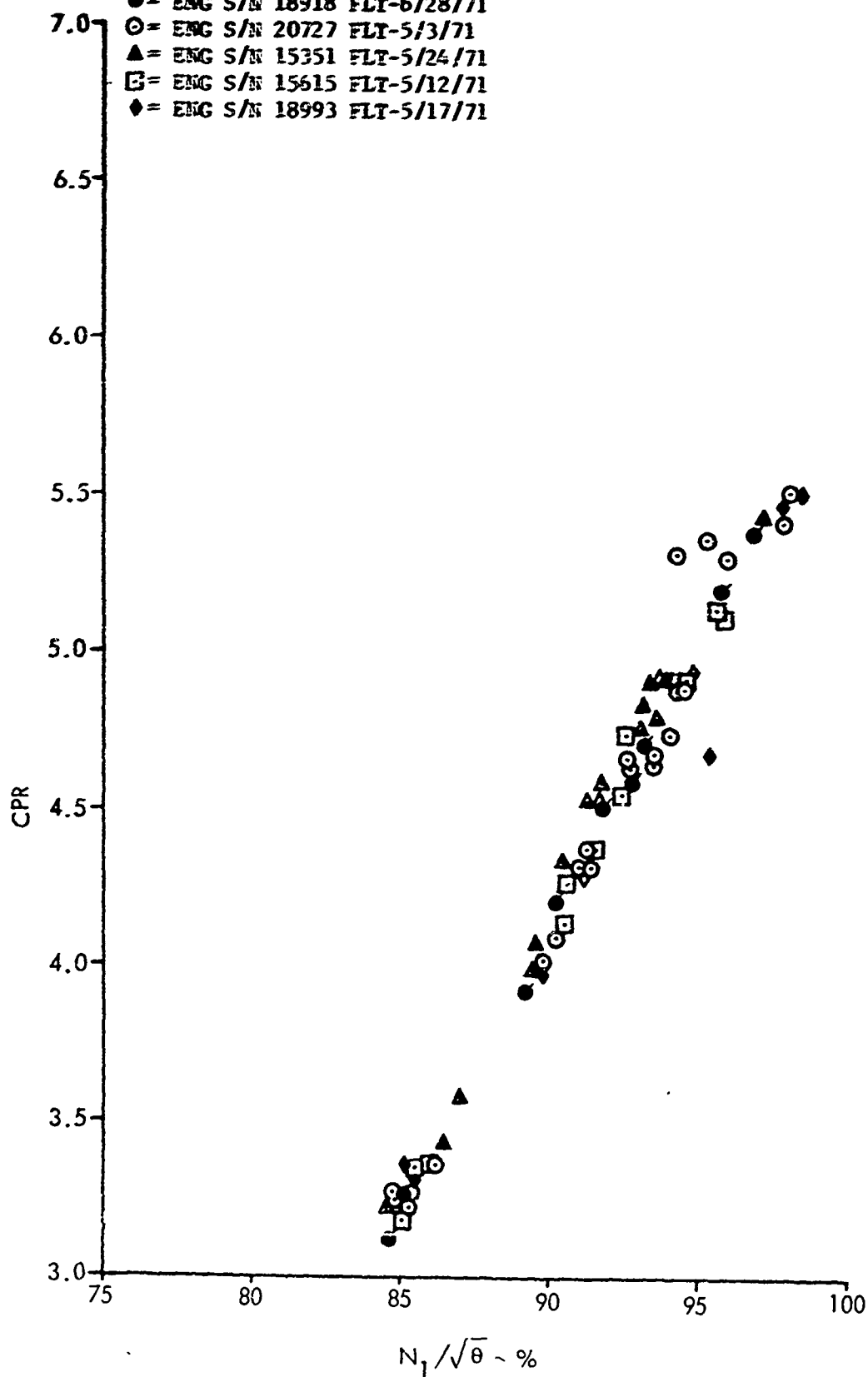


FIGURE 7-47 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

# NONDISCREPANT ENGINES

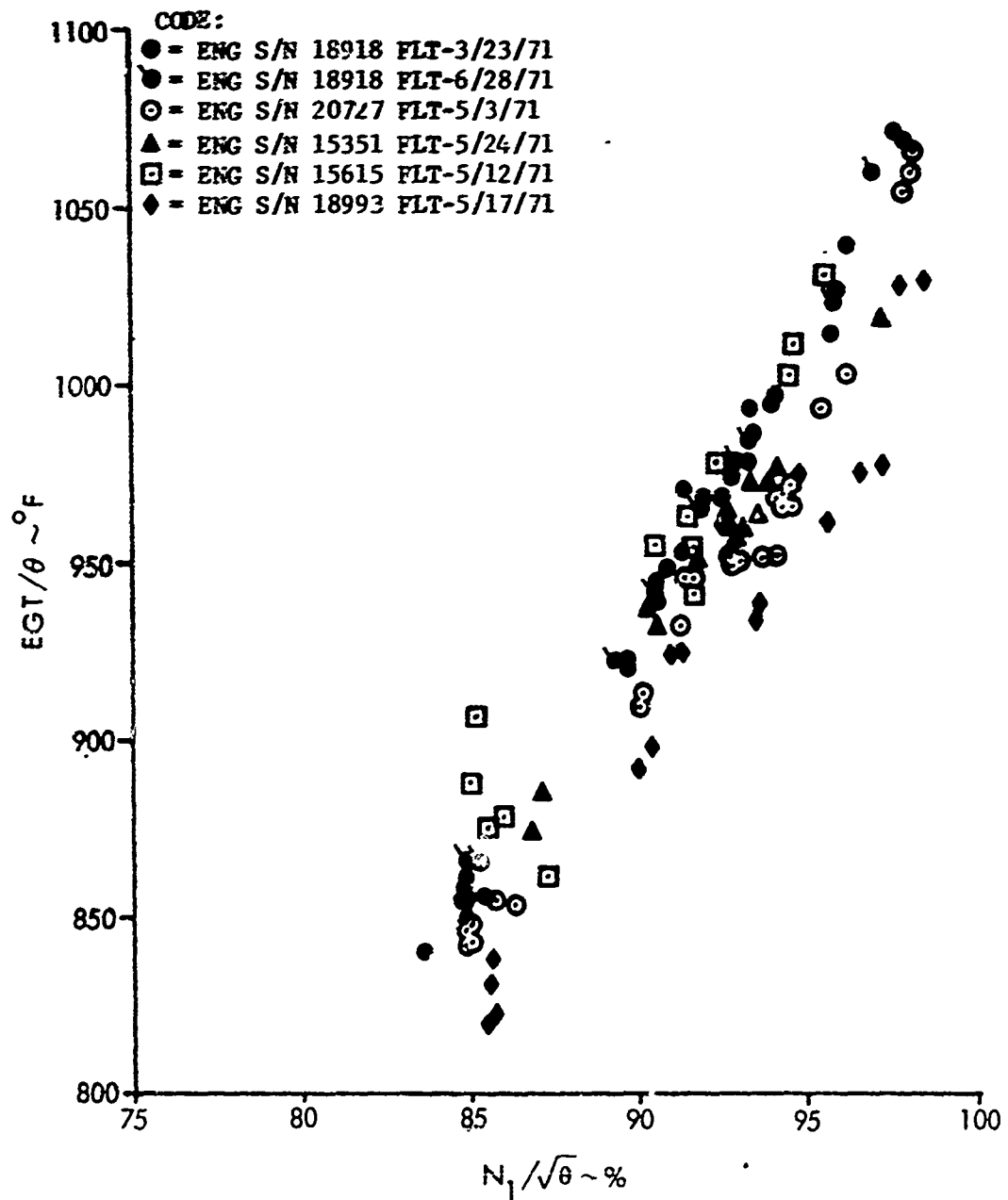


FIGURE 7-48 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

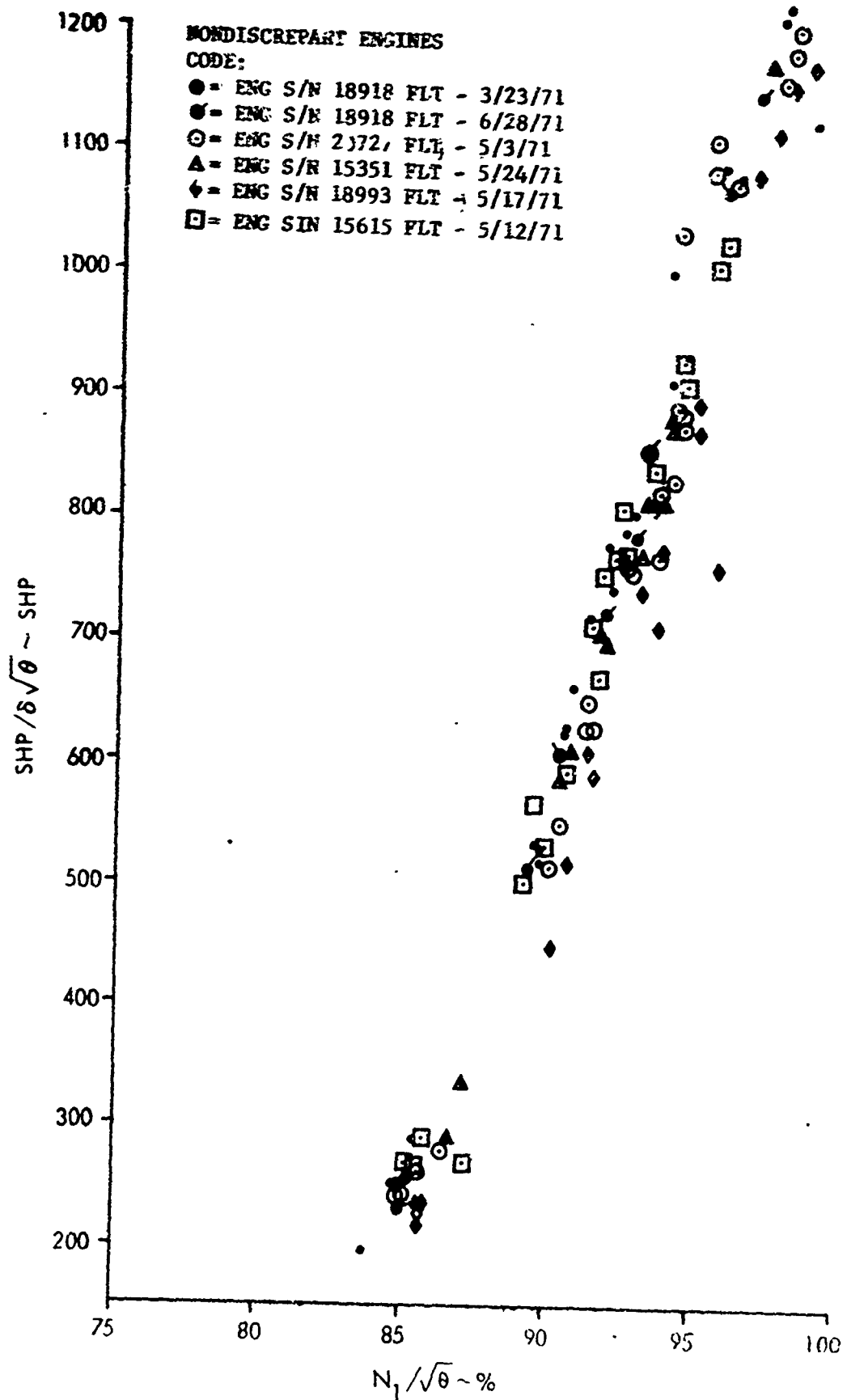


FIGURE 7-49 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

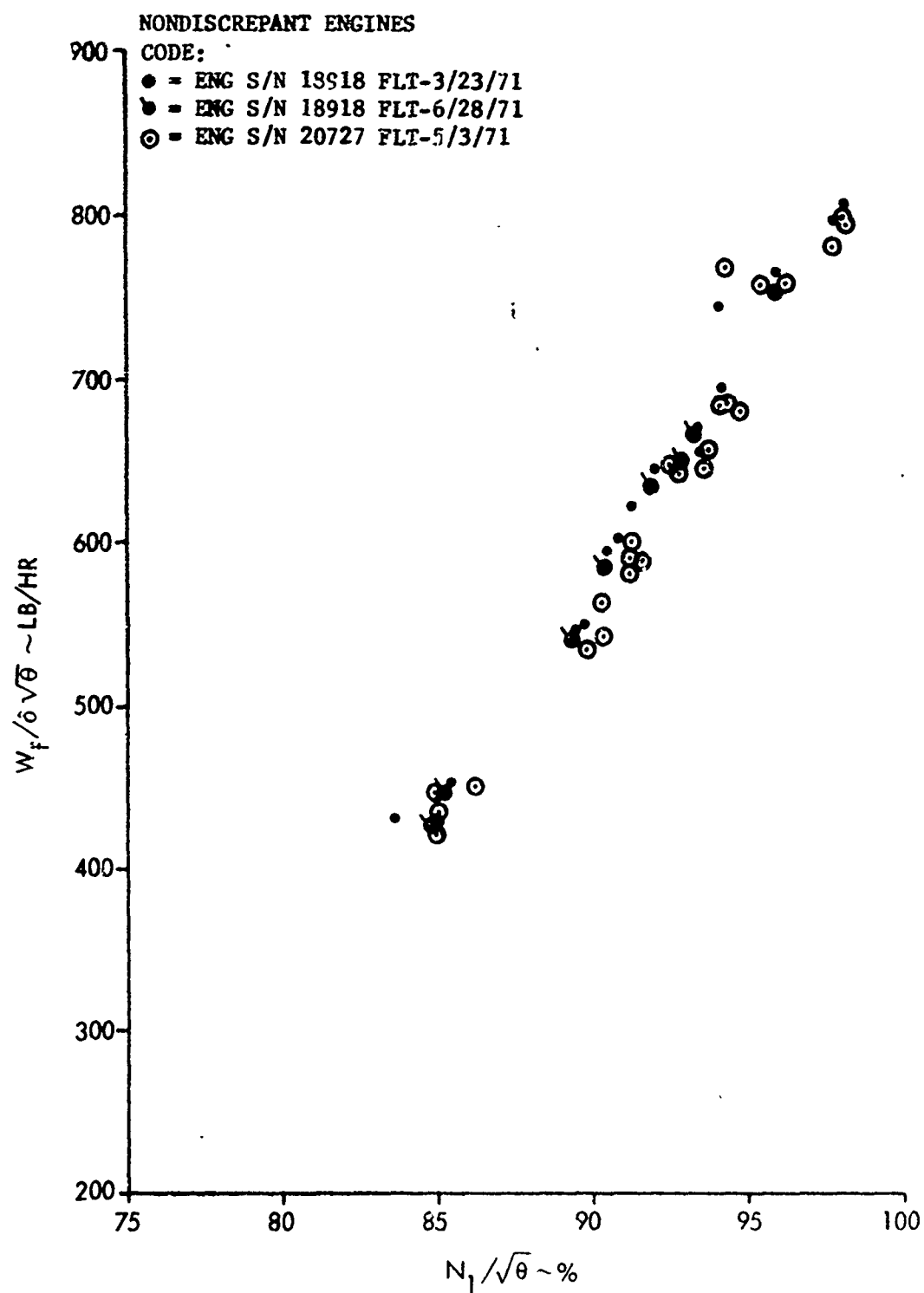


FIGURE 7-50 CORRECTED FUEL FLOW VS CORRECTED  $N_1$  SPEED

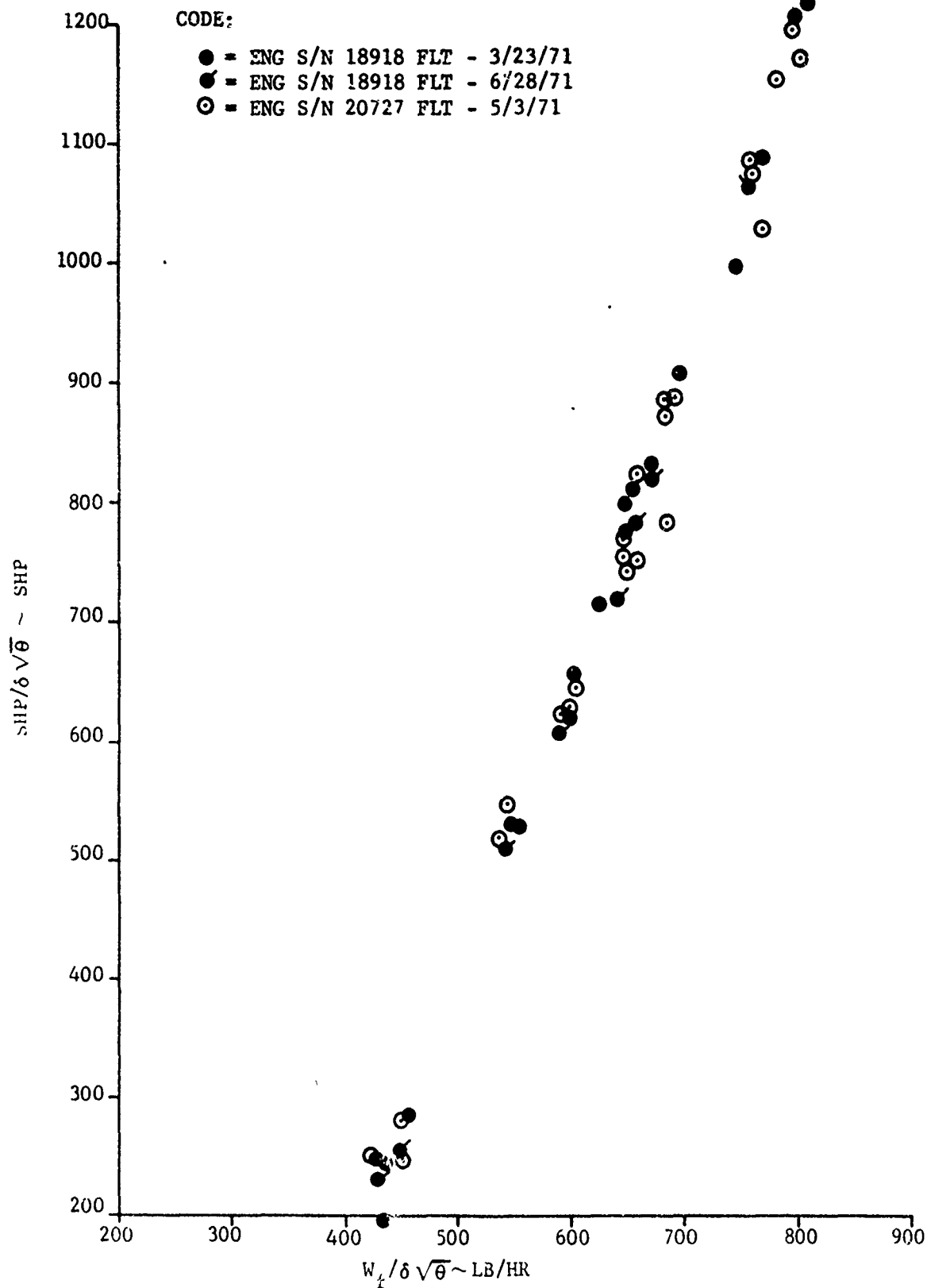


FIGURE 7-51 CORRECTED SHAFT HORSEPOWER VS CORRECTED FUEL FLOW  
NONDISCREPANT ENGINES

S/N 20727 2/19/71

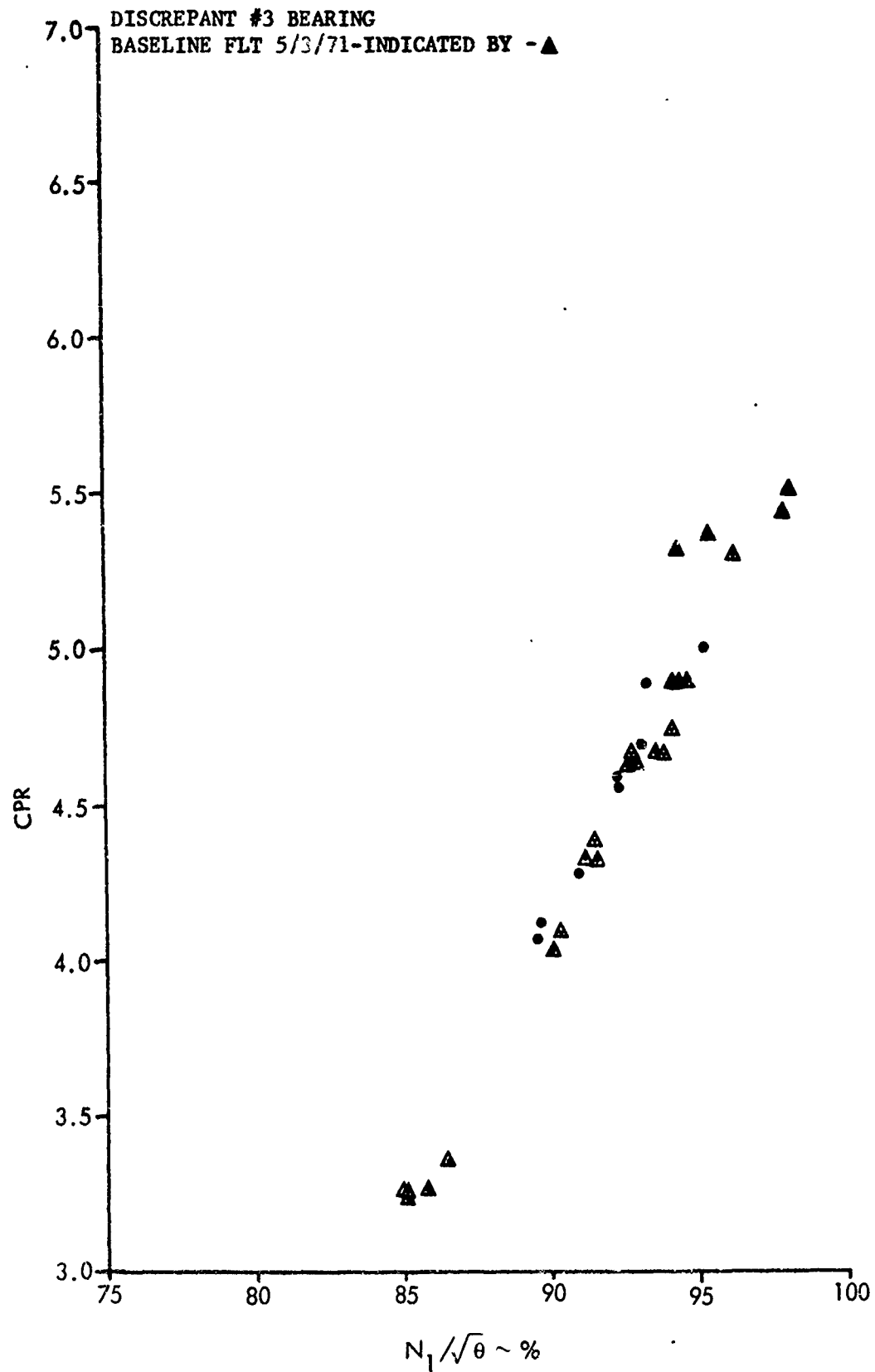


FIGURE 7-52 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

SN20727 2/19/71

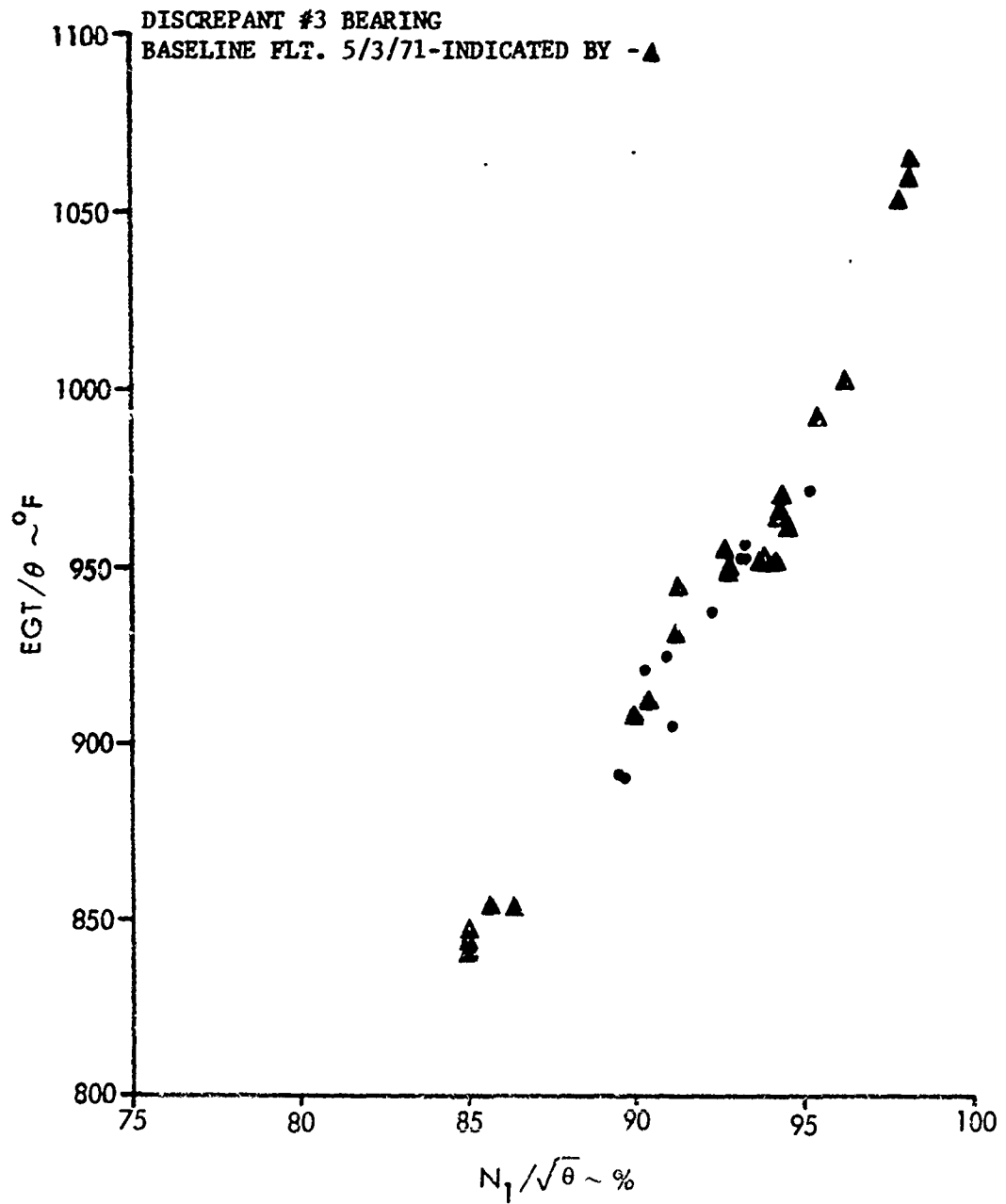


FIGURE 7-53 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

S/N 20727 2/19/71

DISCREPANT #3 BEARING

BASELINE FLT. 5/3/71-INDICATED BY -▲

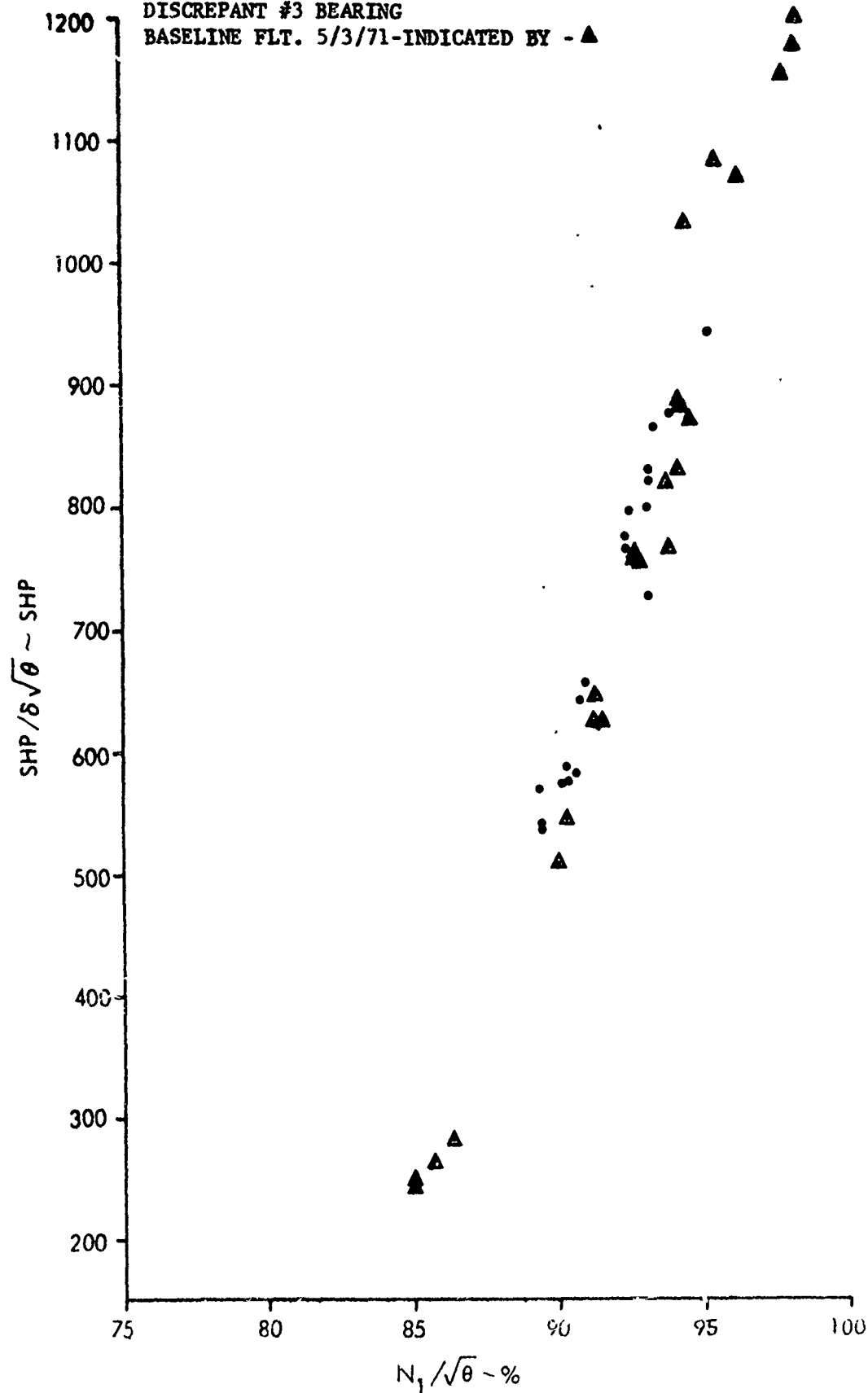


FIGURE 7-54 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

S/N 20727 6/3,4,/71

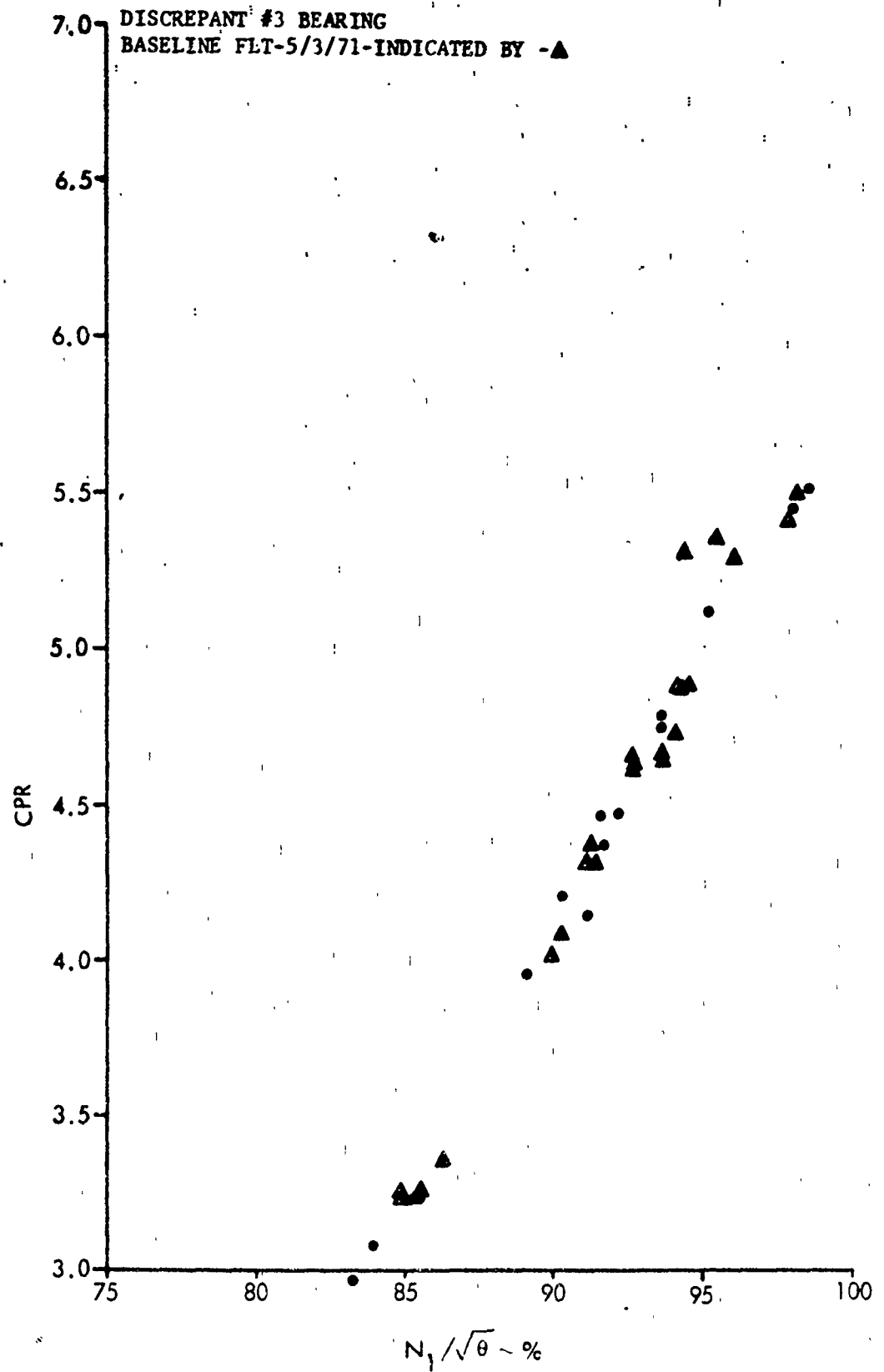


FIGURE 7-55 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

SN20727 6/3,4/71

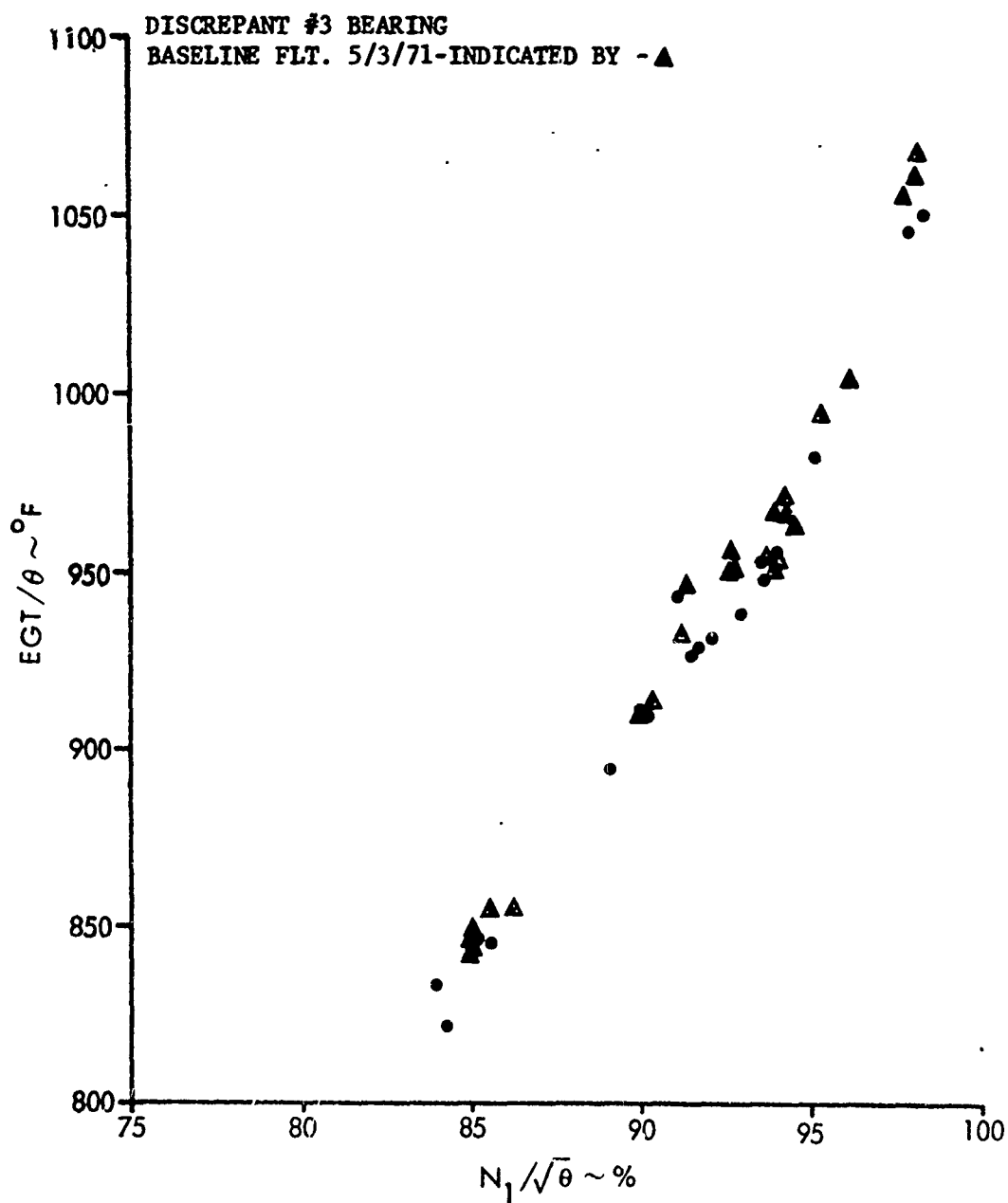


FIGURE 7-56 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

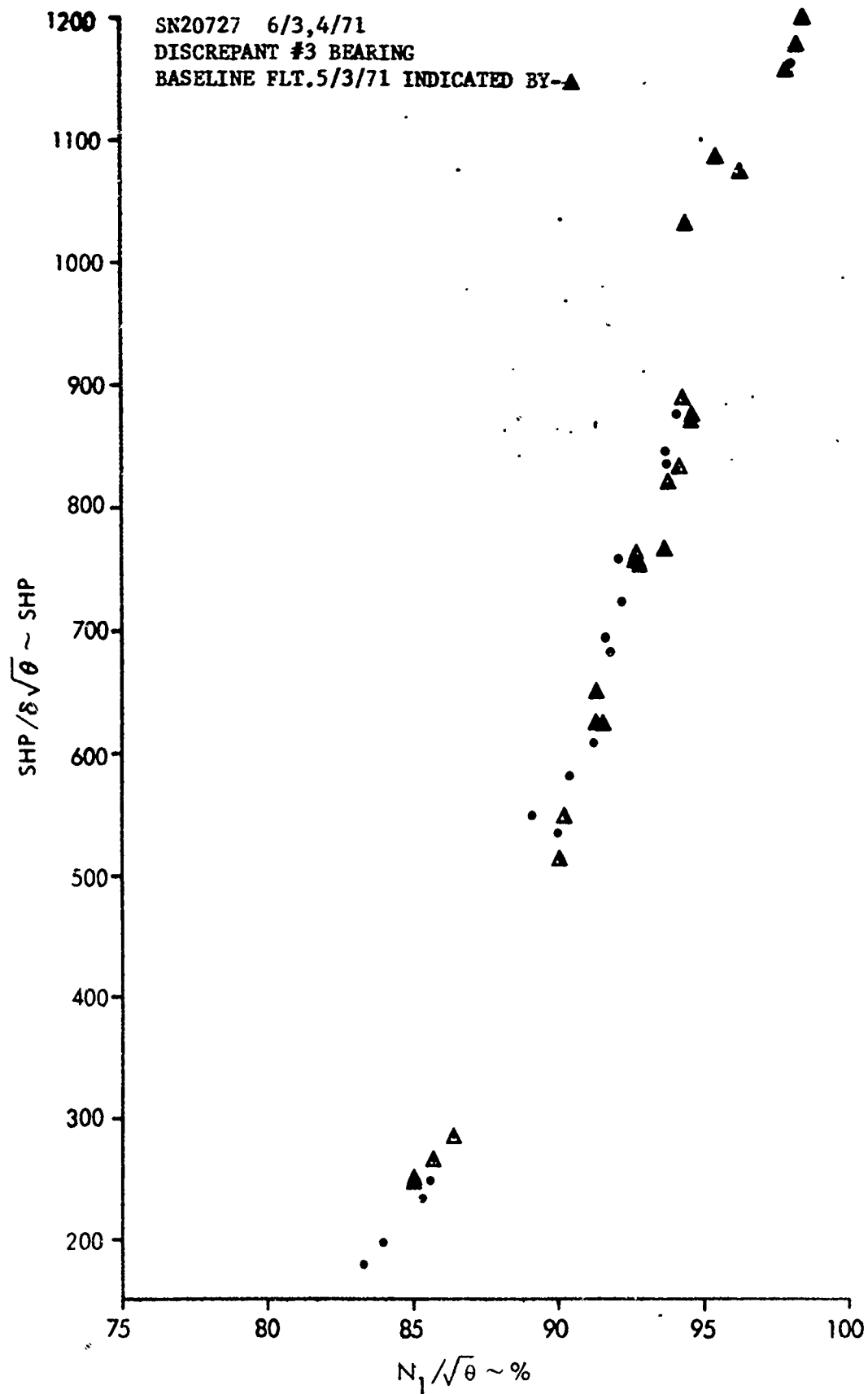


FIGURE 7-57 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

ENG S/N 20727 6/21/71

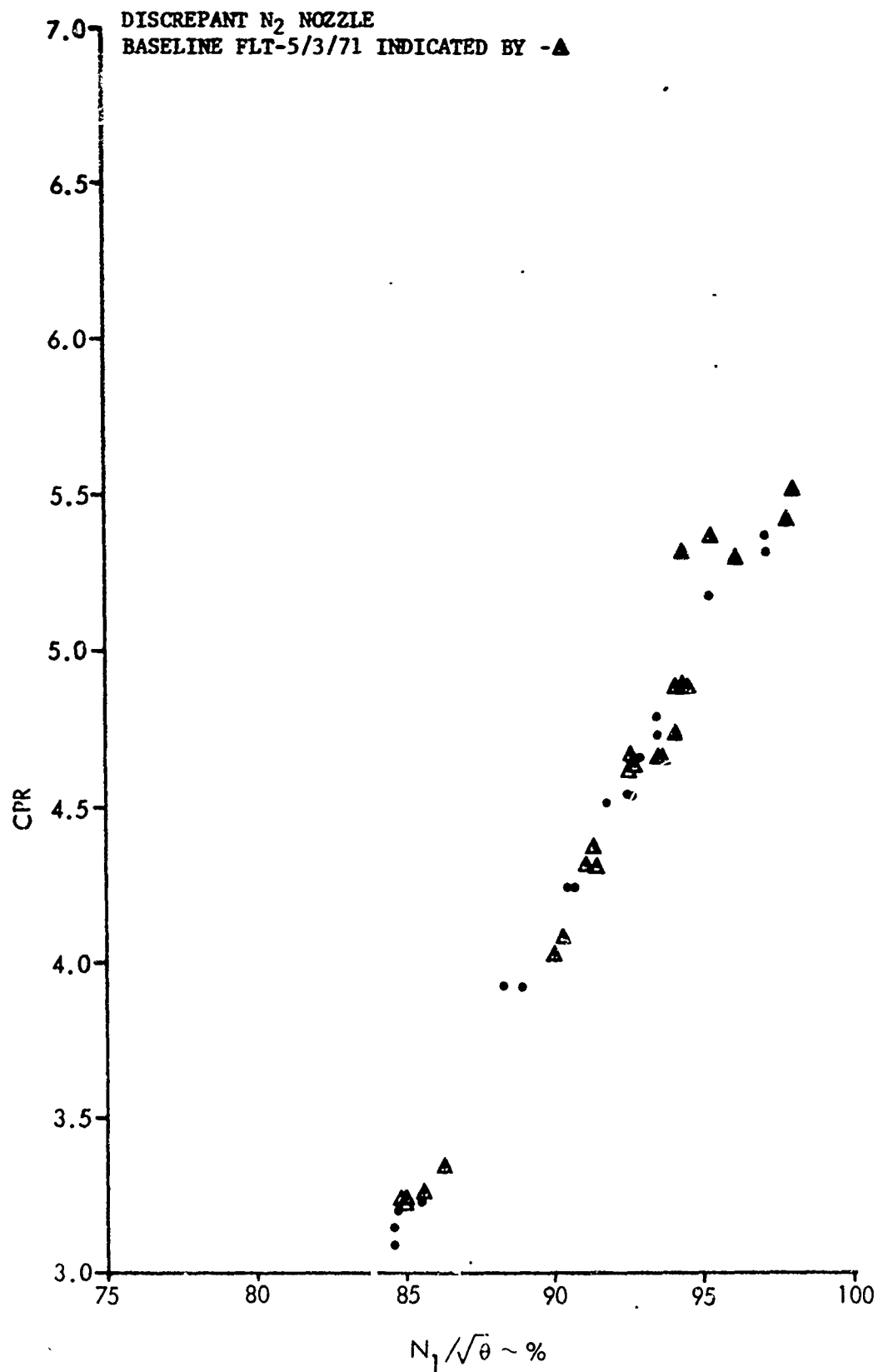


FIGURE 7-58 COMPRESSOR PRESSURE RATIO VS CORRECTED N<sub>1</sub> SPEED

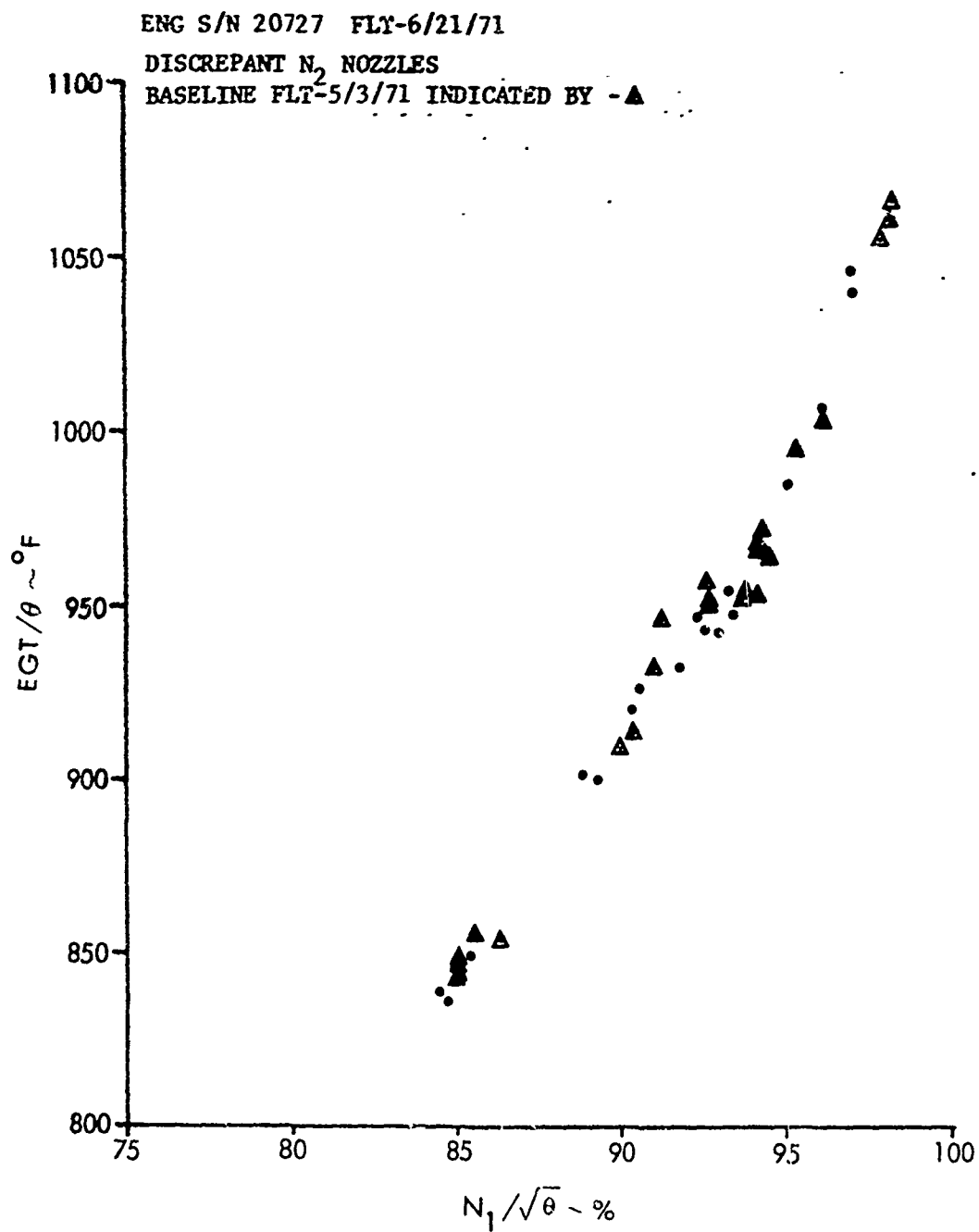


FIGURE 7-59 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED N<sub>1</sub> SPEED

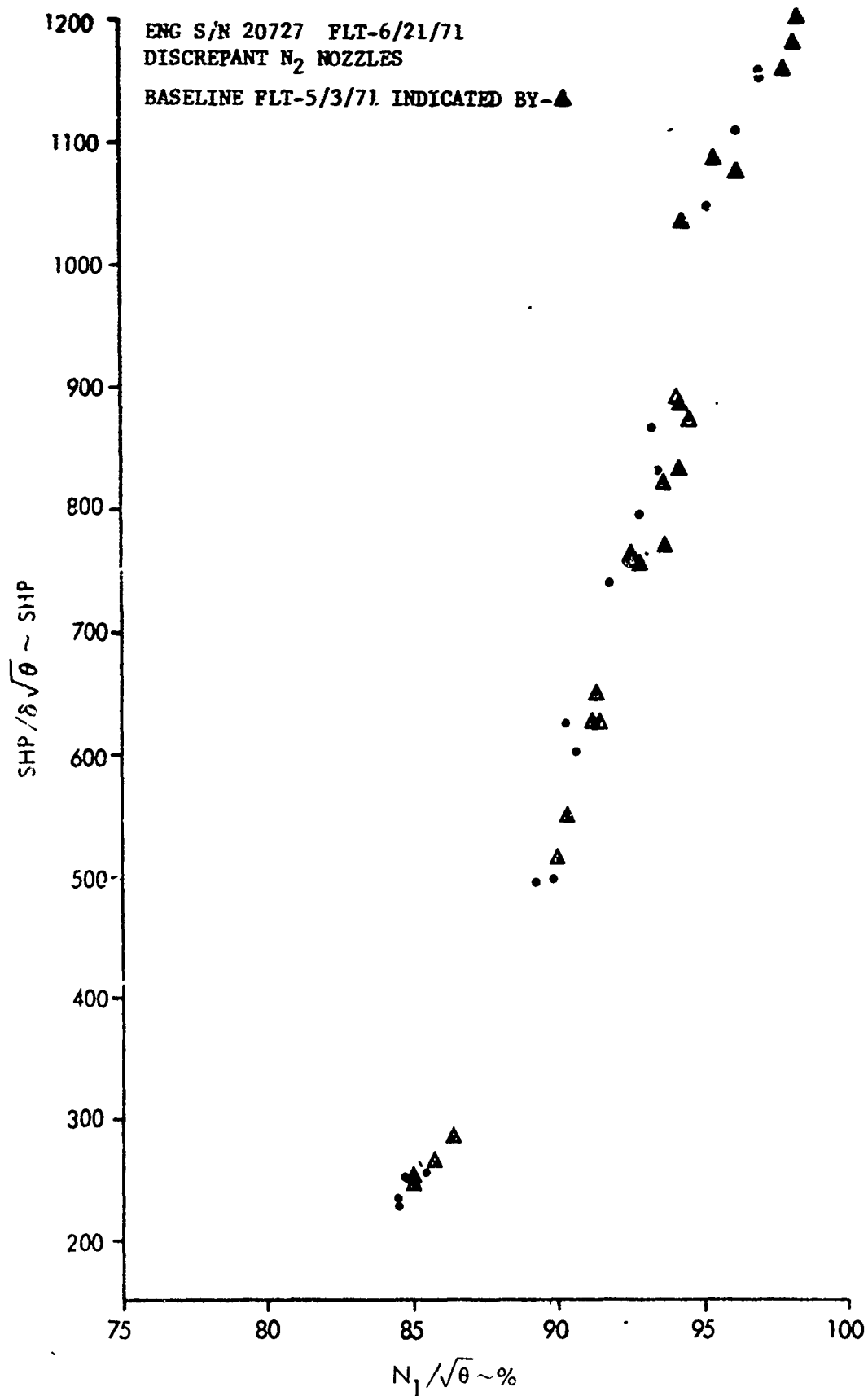


FIGURE 7-60 CORRECTED SHAFT HORSEPOWER VS CORRECTED N<sub>1</sub> SPEED

SN20727 3/17/71 - 3/18/71

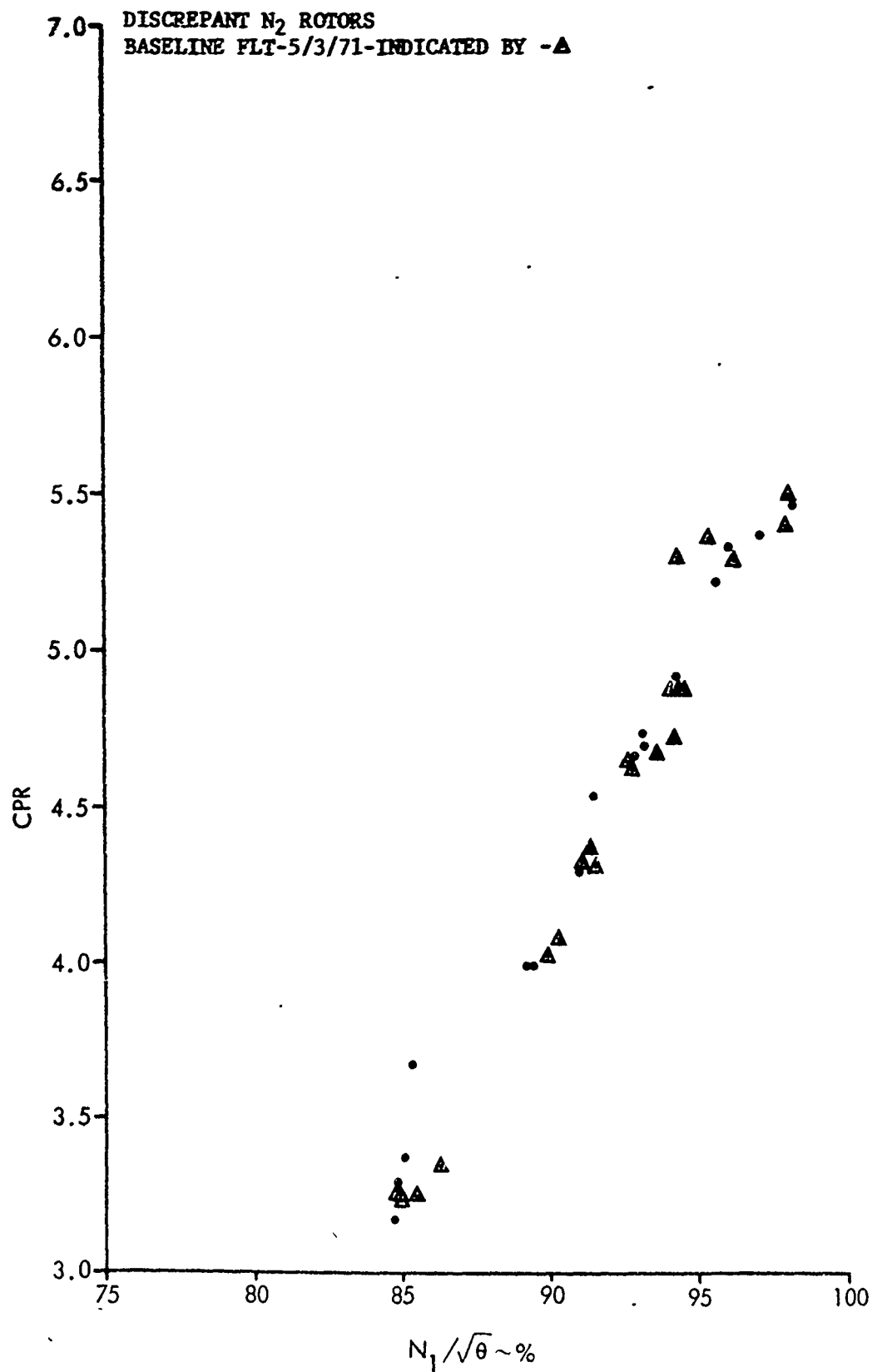


FIGURE 7-61 COMPRESSOR PRESSURE RATIO VS CORRECTED N<sub>1</sub> SPEED

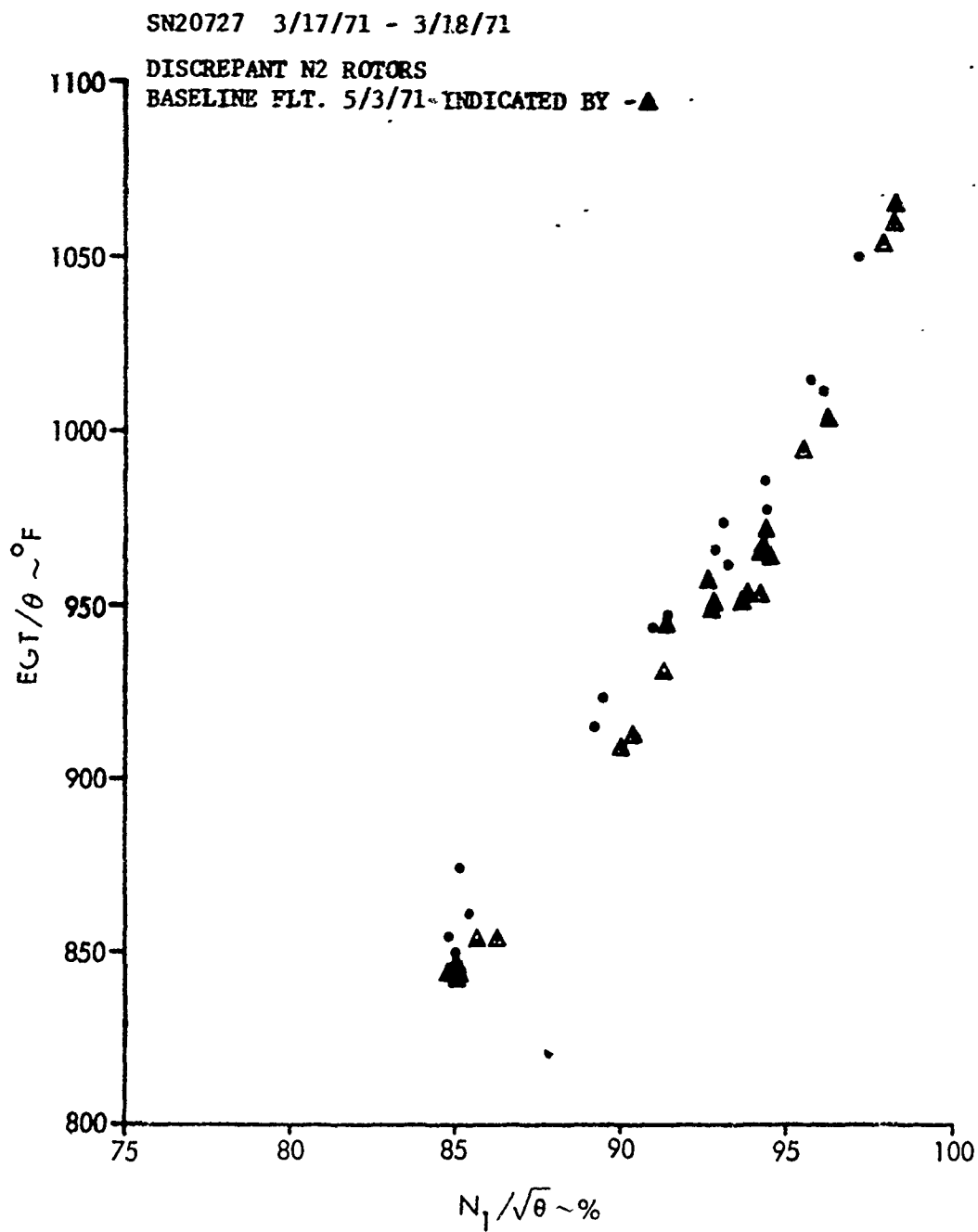


FIGURE 7-62 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

ENG S/N 20727 3/17,18/71

DISCREPANT N2 ROTORS

BASELINE FLT-5/3/71-INDICATED BY -▲

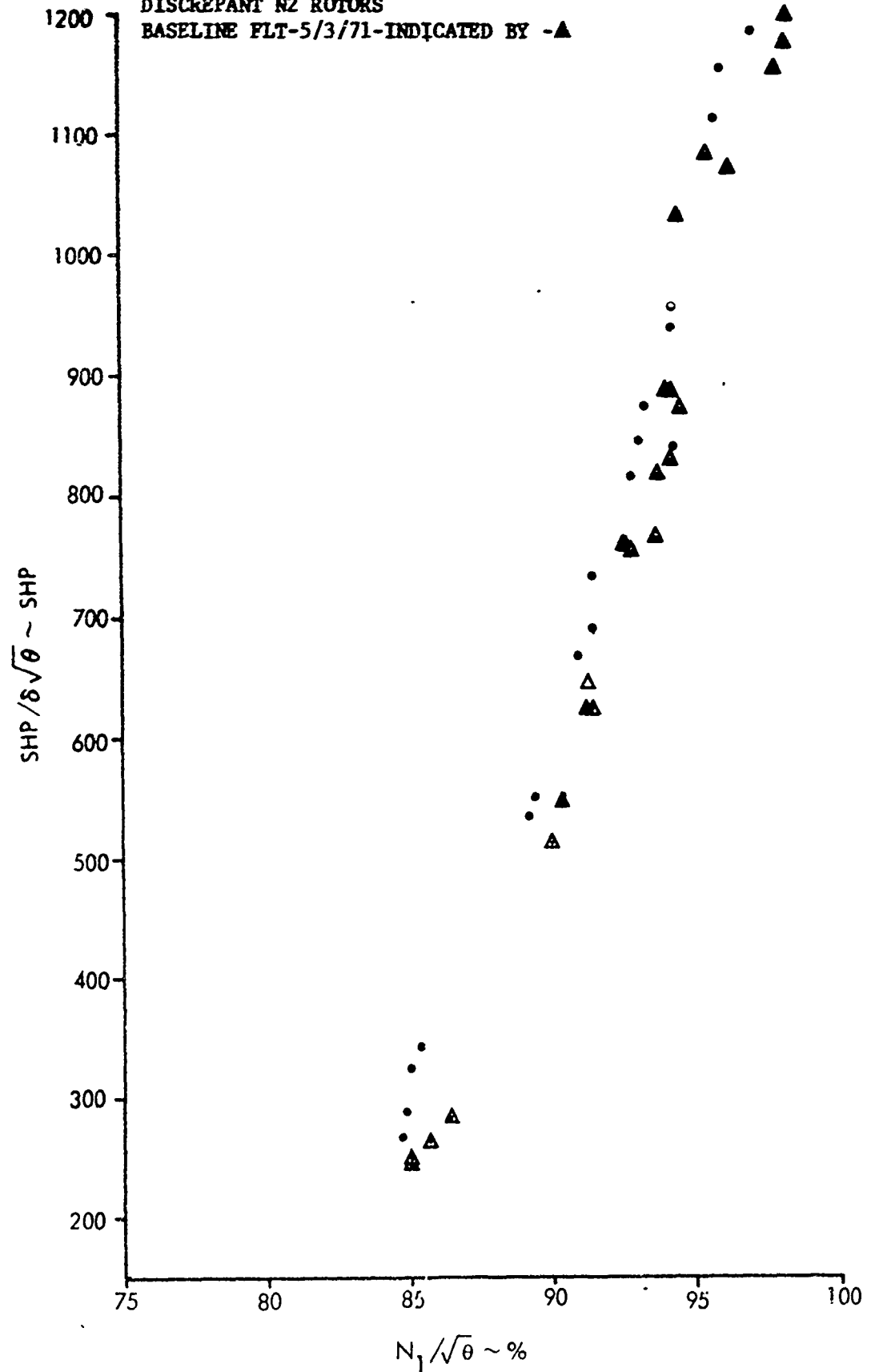


FIGURE 7-63 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

do not appear to be sufficiently damaged to cause changes in the thermodynamics performance of the engine.

- b) Discrepant  $N_2$  nozzle engine flight test (21 June 1971) also showed no performance change from the baseline values (see figures 7-58 through 7-60).
- c) It appears that the selected degraded No. 3 bearings and  $N_2$  nozzles would provide considerable engine running time before the implanted engine could be rejected due to poor engine performance.
- d) Direct performance comparison of a baseline and discrepant power turbine engines show slight increase in exhaust gas temperature and shaft horsepower (see figures 7-61 through 7-63). Both parameters are higher than the baseline values. Higher EGT can be attributed to the defective power turbine; however, lower shaft horsepower would have been expected. These are the typical indications of a problem in the power turbine assembly section. It is difficult to accurately assess the data because the baseline data was obtained over a month after the discrepant power turbine engine flight test. During this period, there may have been some adjustments made on the engine which could have modified the engine power output.

Discrepant parts implanted in engine S/N 15615 consisted of compressor, No. 2 bearings, and gas producer turbine ( $N_1$ ) nozzles. Baseline performance values were obtained from the flight conducted on 12 May 1971. The following results were determined from the engine gas flow analysis:

- a) Figures 7-64 through 7-66 show the effect of degraded compressor on engine performance. Direct comparison of the baseline and discrepant engine performance characteristics indicate that only the compressor pressure ratio and EGT were affected by the damaged compressor. The compressor pressure ratio decreased slightly and the EGT was slightly higher. No change in engine shaft horsepower indicates that the compressor damage is minor. Otherwise, the compressor would have reduced the engine air flow and air pressure enough to affect the engine shaft horsepower. The engine fuel flow rate could not be compared because it was not recorded during the baseline flight. However, it appears that the engine fuel flow rate was not affected based on the data of other performance parameters; no change

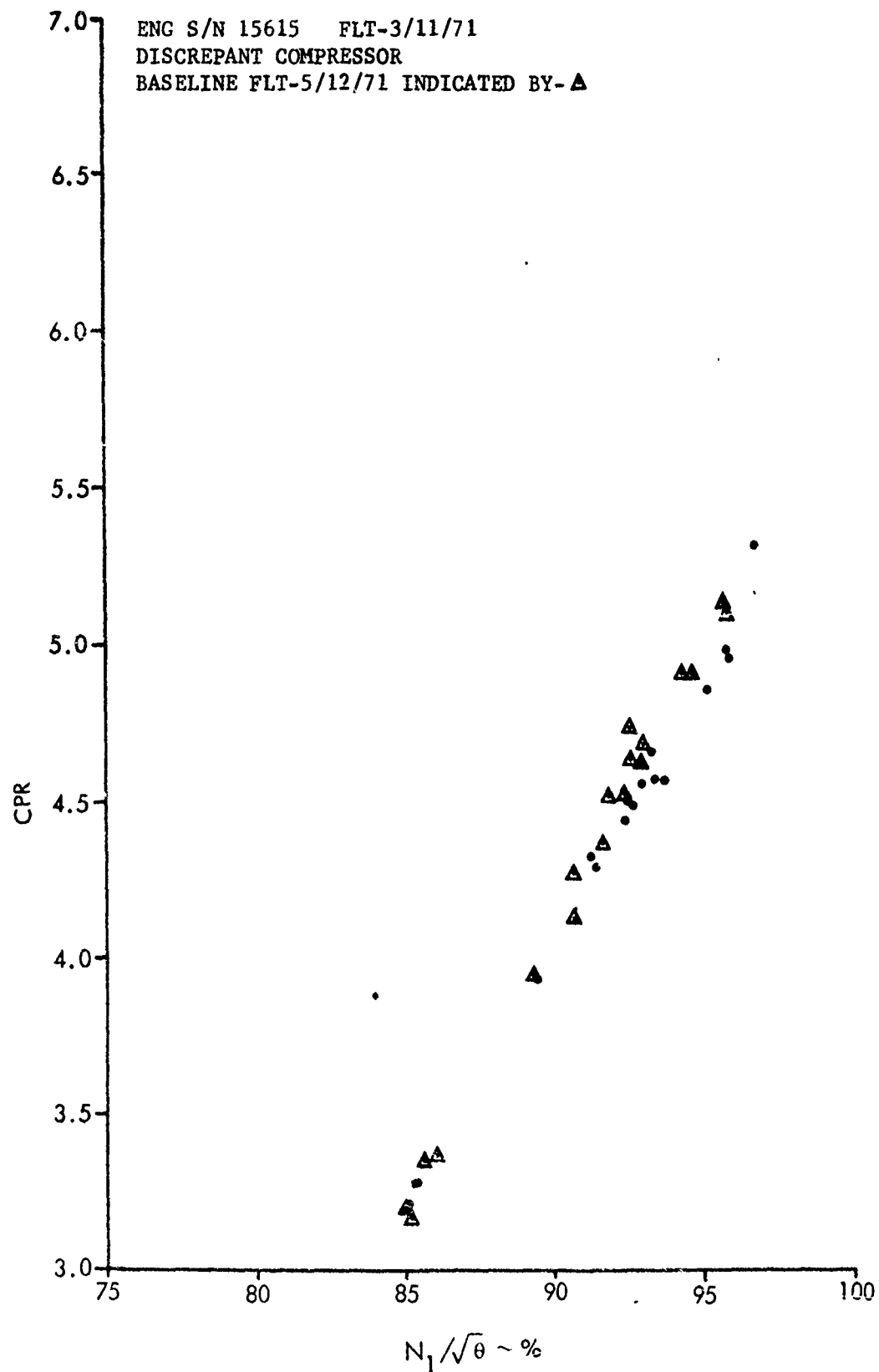


FIGURE 7-64 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

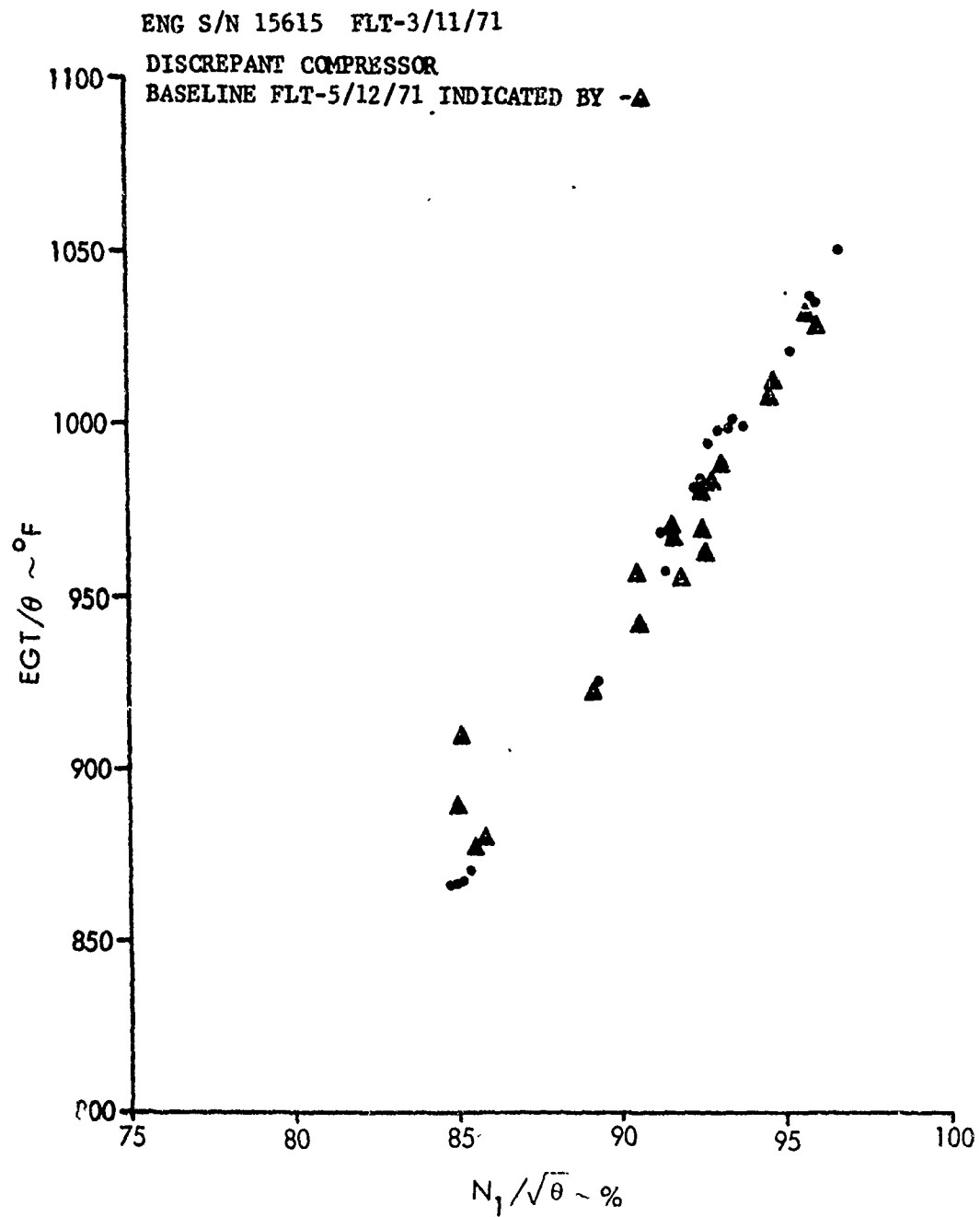


FIGURE 7-65 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED N<sub>1</sub> SPEED

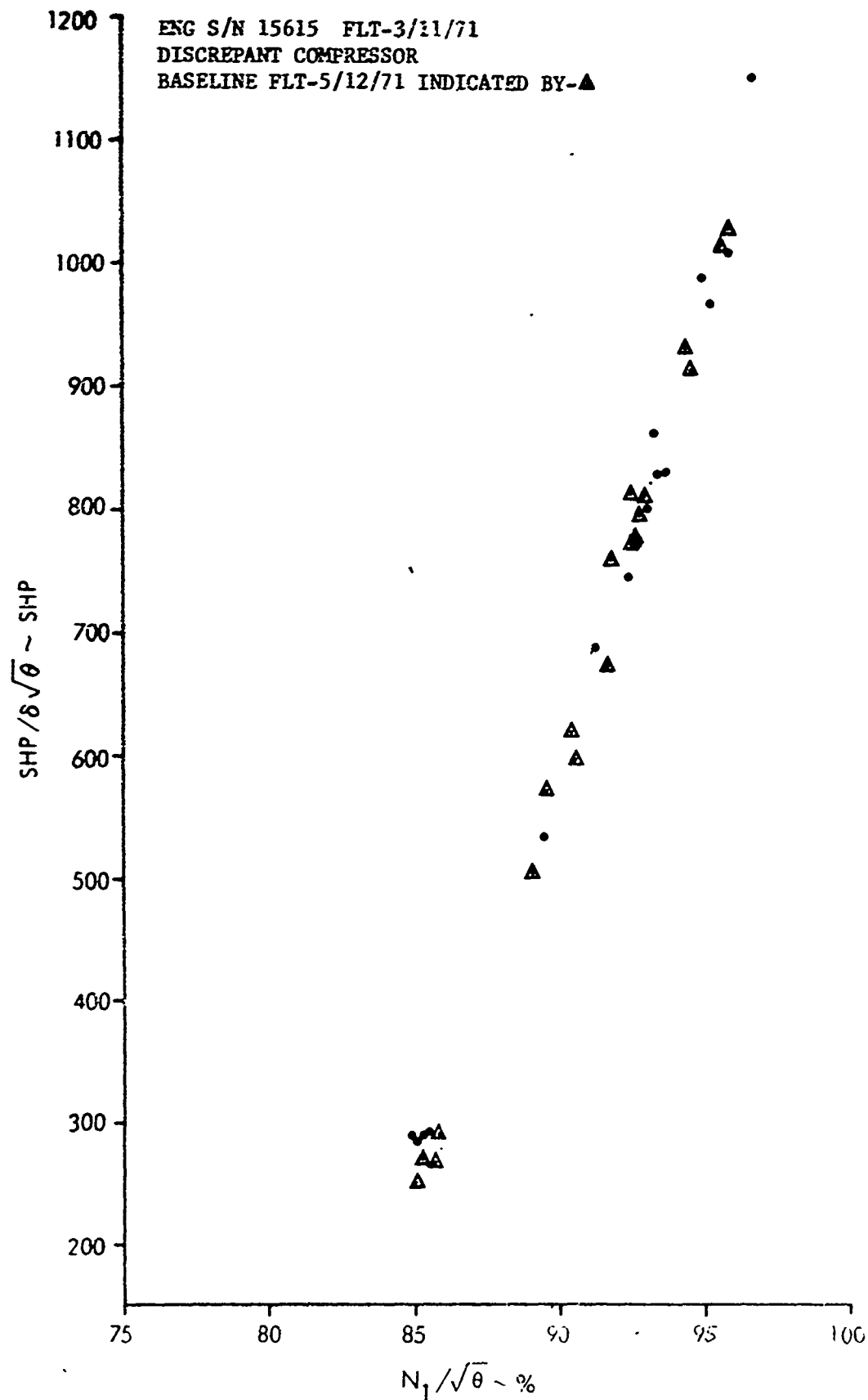


FIGURE 7-66 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

in SHP and slightly higher EGT. Typically, increase in EGT results from the reduced engine air flow which increases the fuel-air mixture in the engine combustion process.

- b) Figures 7-67 through 7-69 show that the implanted No. 2 bearings were not sufficiently damaged to degrade the engine performance.
- c) Figures 7-70 through 7-72 indicated that the degree of  $N_1$  nozzle damage is in the same category as the previous bearing damage. The discrepant  $N_1$  nozzles had no significant effect on engine performance characteristics.

Engine S/N 15351 was used to implant the defective power turbine (No. 4) bearing specimens and power turbine. Five flight tests were performed consisting of three flights with discrepant No. 4 bearings, one flight with a degraded power turbine, and one baseline flight. The engine performance data of these flights are presented in figures 7-73 through 7-84. Significant results of these flight tests are as follows:

- a) The same bearing specimen was used for two flights, 24 February 1971 and 3 March 1971. Direct comparison of the two flight tests and baseline flight performance data showed a slight decrease in exhaust gas temperature, and no change in compressor performance or engine shaft horsepower (see figures 7-73 through 7-78). The other degraded bearing sample (26 April 1971) had no effect on normal engine performance values (see figures 7-79 through 7-81).
- b) No significant performance degradation was observed on the discrepant power turbine (see figures 7-82 through 7-84).

Three discrepant parts were tested using engine S/N 18993; gas producer turbine ( $N_1$ ) nozzles, power turbine ( $N_2$ ) nozzles and compressor. Figures 7-85 through 7-93 present the comparison of the degraded parts and baseline engine performance. Significant effects of the discrepant parts are the following:

- a) The data from the damaged  $N_1$  nozzle implants, figures 7-85 through 7-87, show that the primary performance indicators (compressor pressure ratio and EGT) were not affected. The slight increase in indicated shaft horsepower of the discrepant engine is questionable because the flight test was conducted during the period of 17 February to 11 March, when a problem was encountered in the calibration of the engine torque data.

ENG S/N 15615 5/27/71

DISCREPANT #2 BEARING

BASELINE FLT - 5/12/71 INDICATED BY -▲

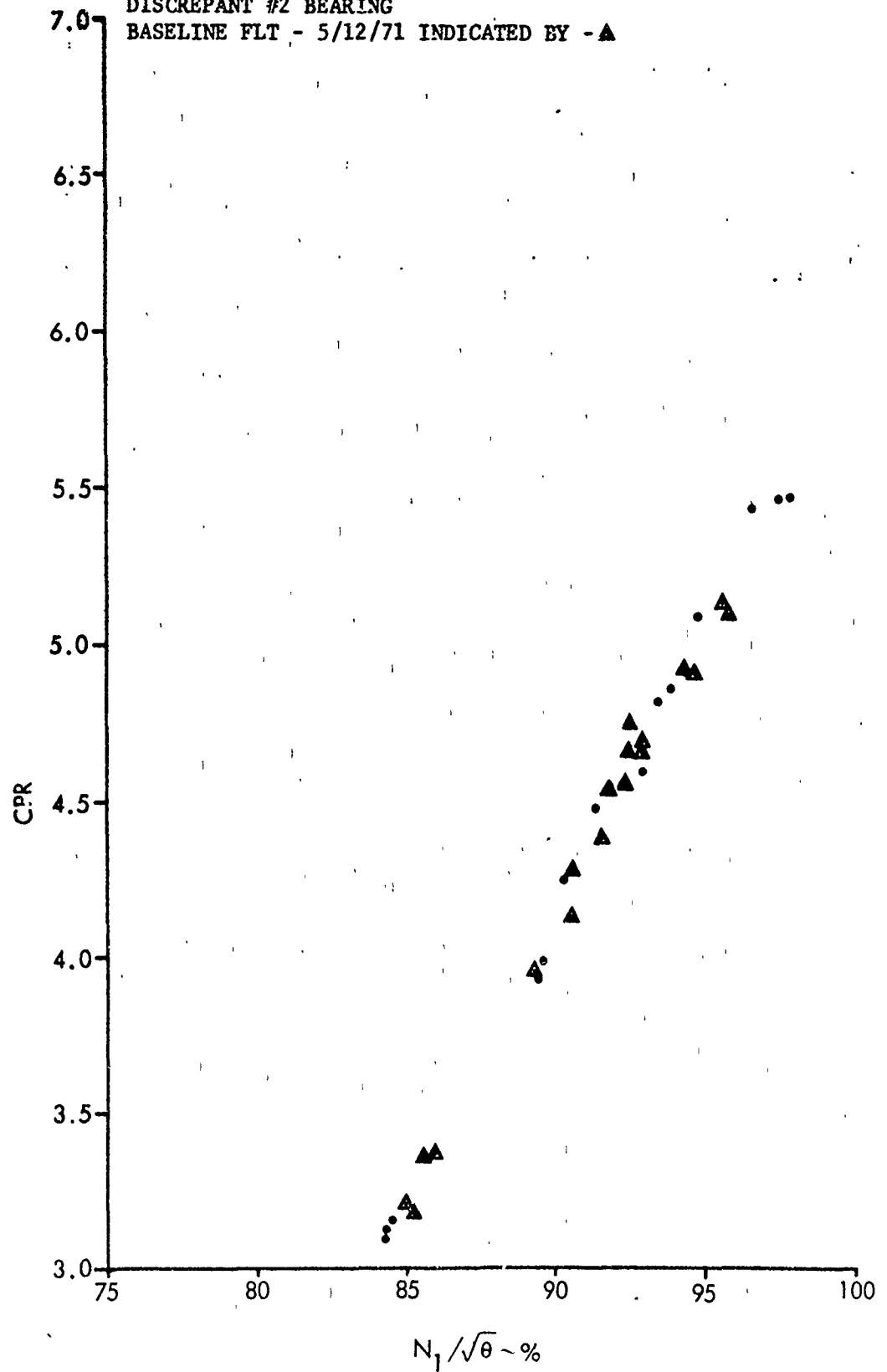


FIGURE 7-67 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

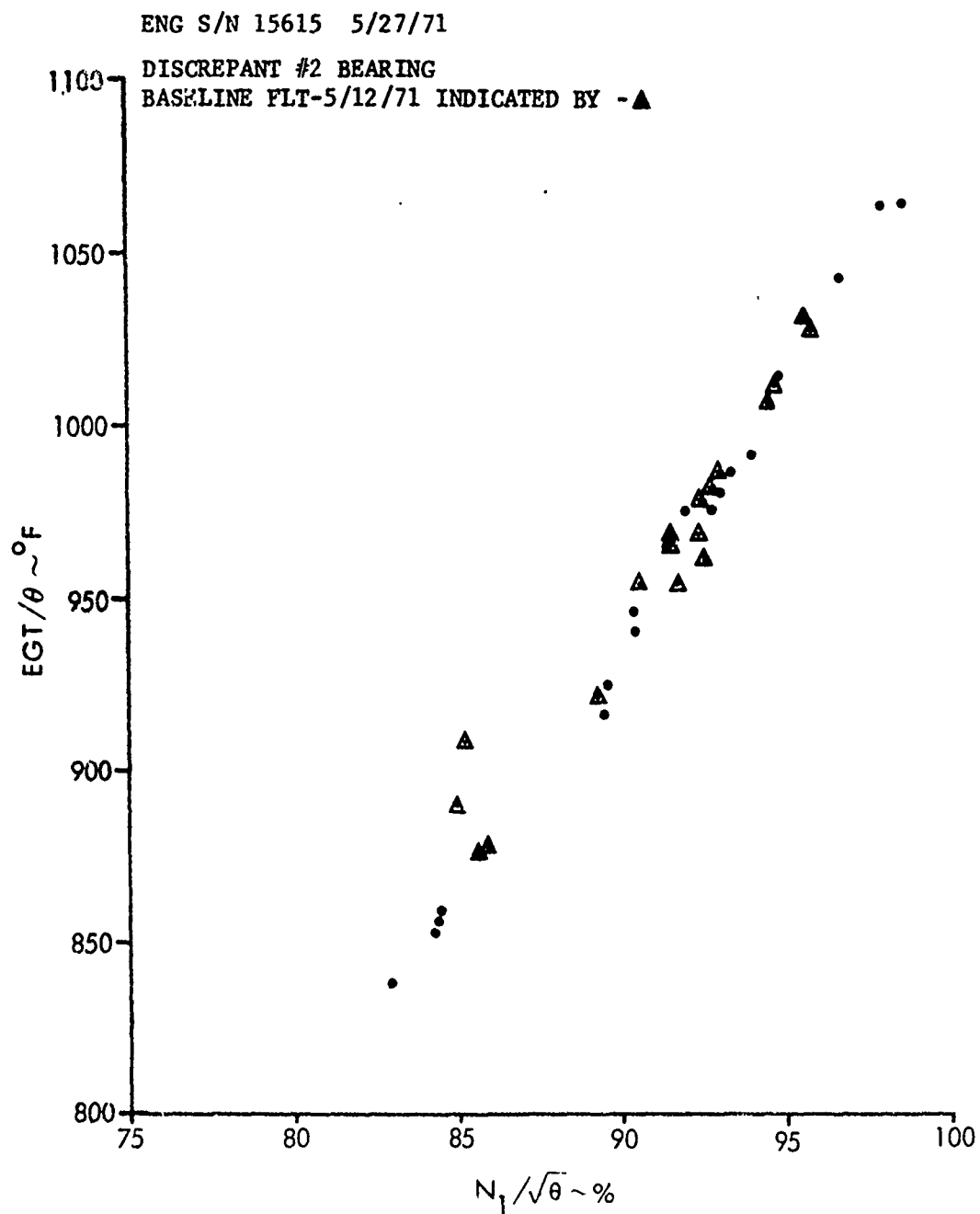


FIGURE 7-68 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

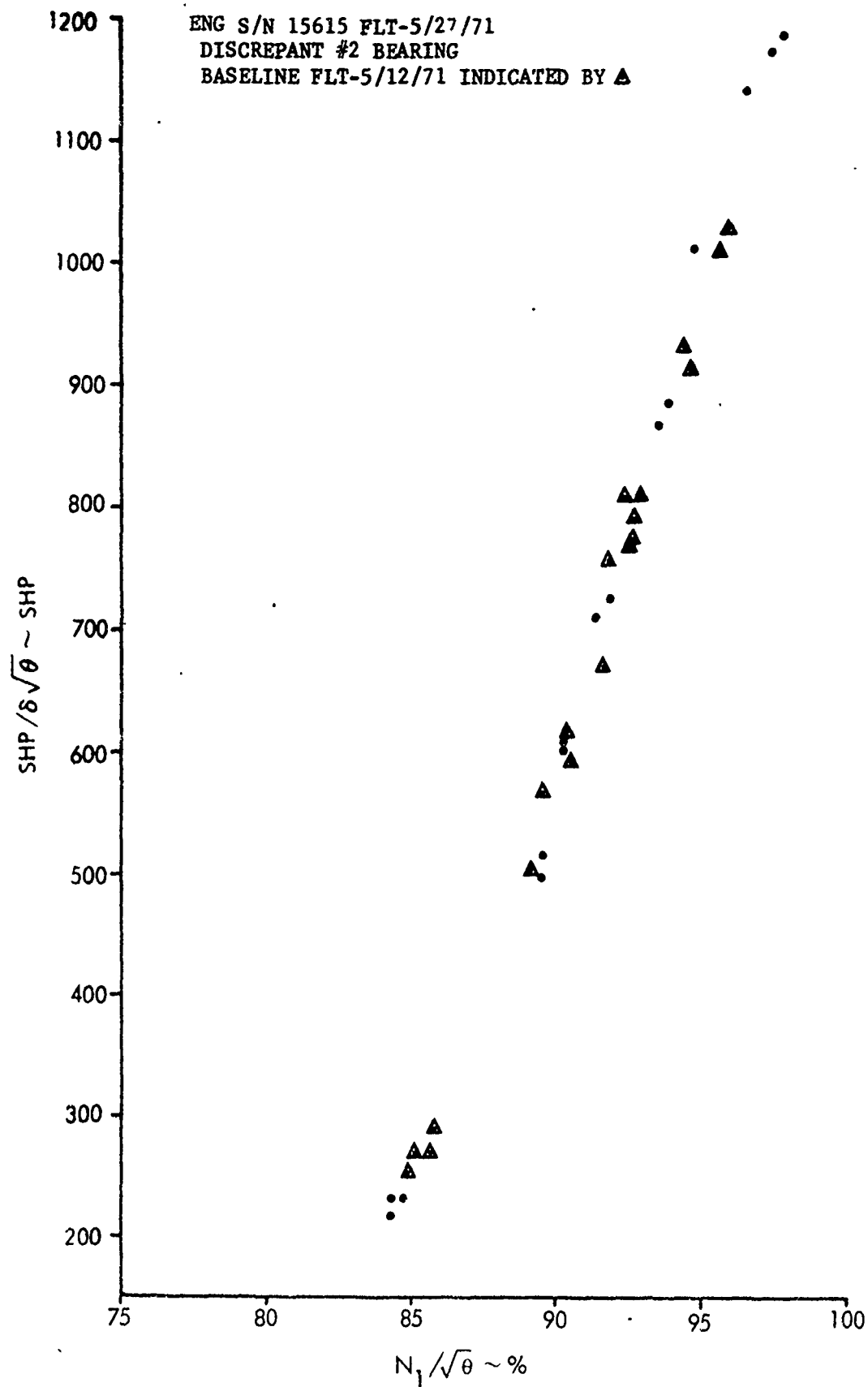


FIGURE 7-69 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

ENG S/N 15615 6/17/71

DISCREPANT  $N_1$  NOZZLES  
BASELINE FLT-5/12/71 INDICATED BY  $\Delta$

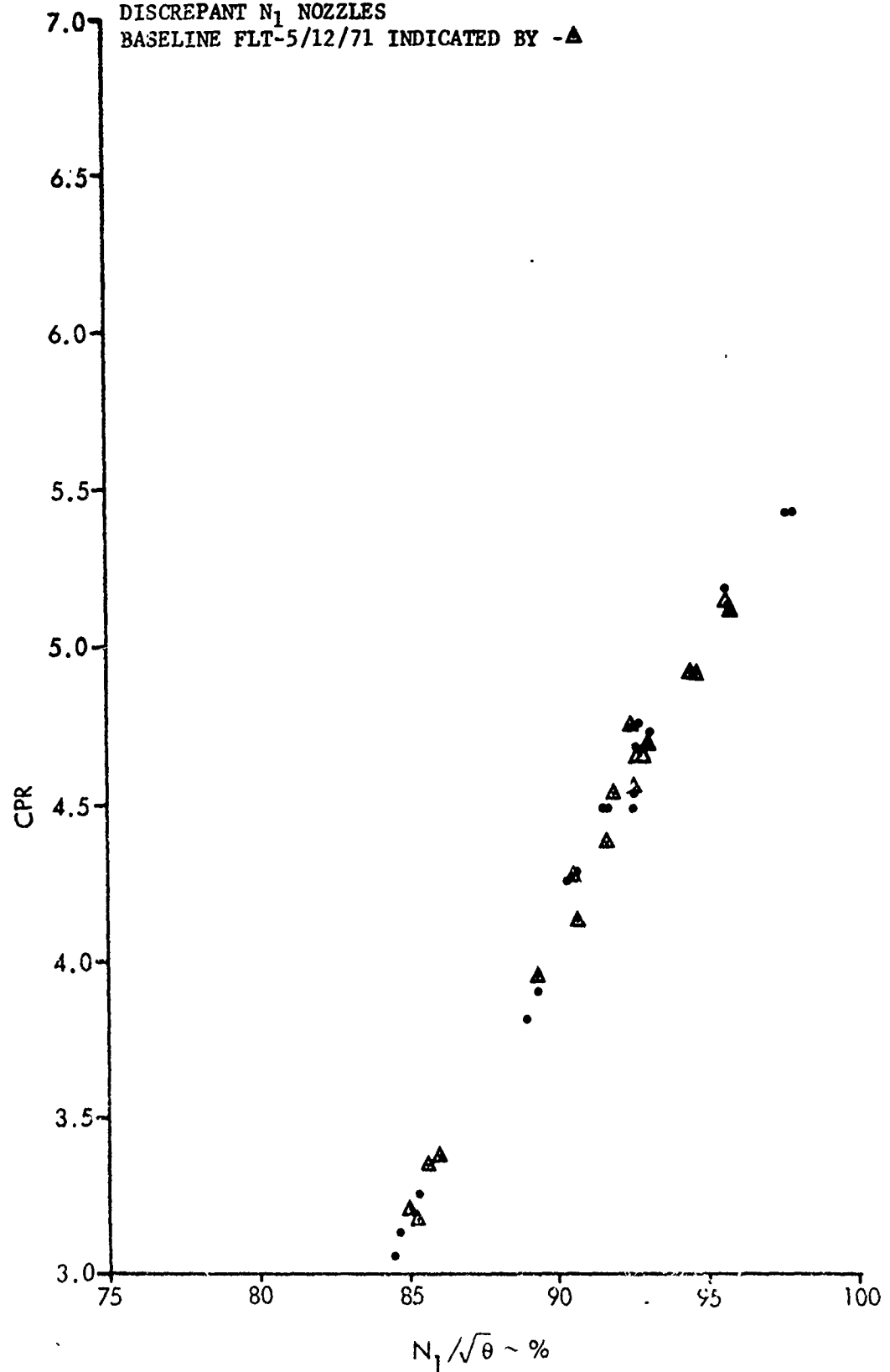


FIGURE 7-70 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

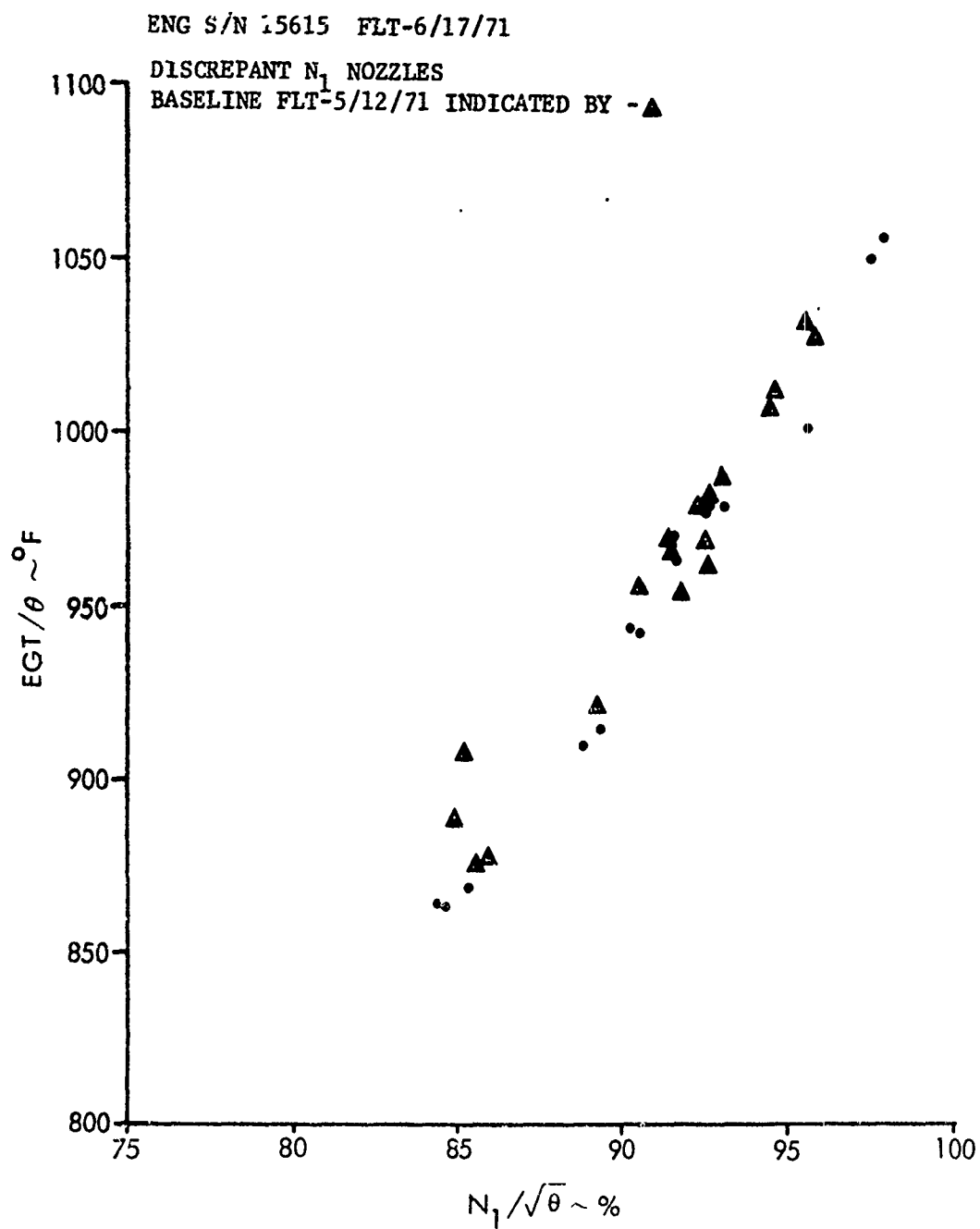


FIGURE 7-71 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

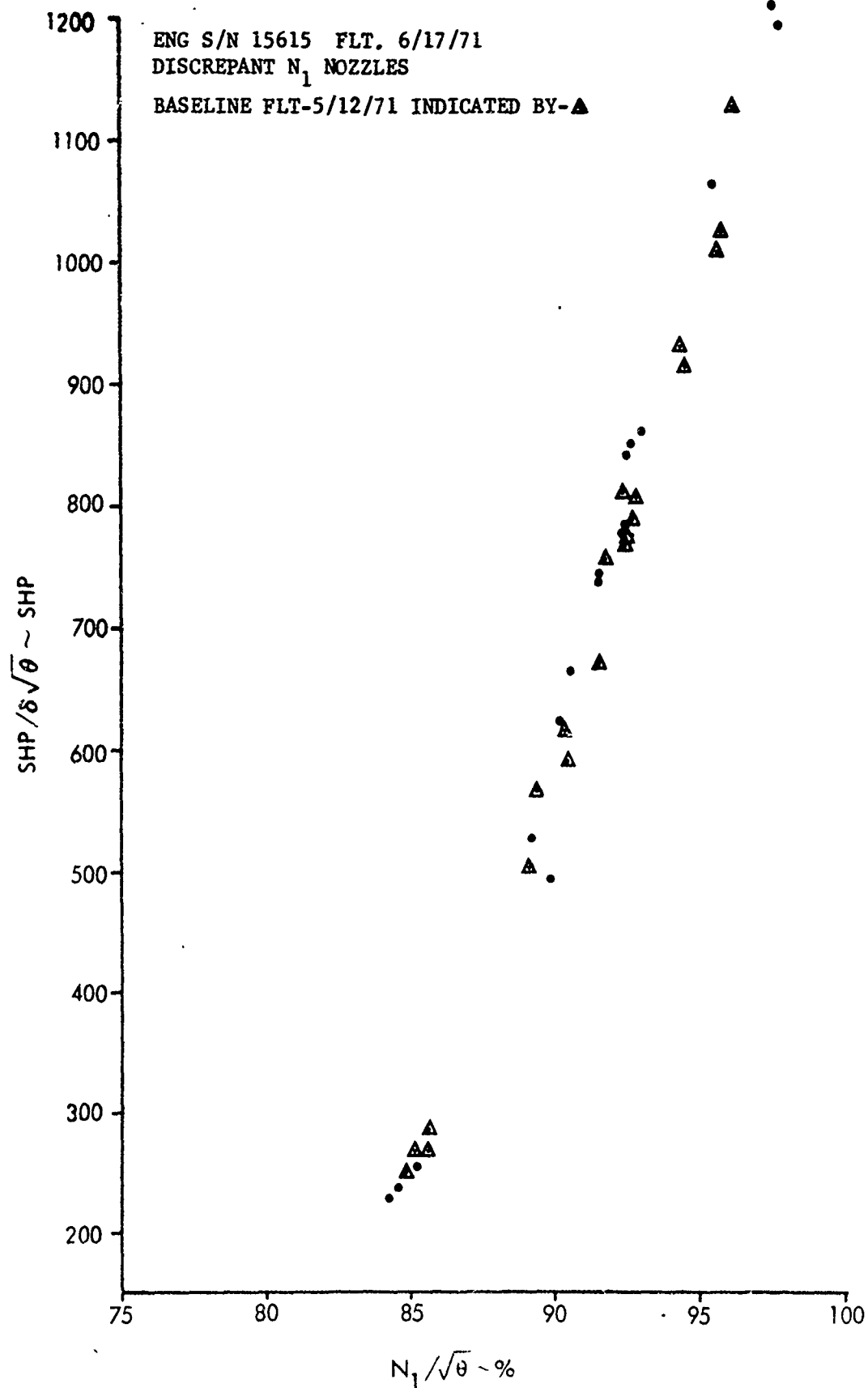


FIGURE 7-72 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

S/N 15351 2/24/71

DISCREPANT #4 BEARING

BASELINE FLT-5/24/71 INDICATED BY -▲

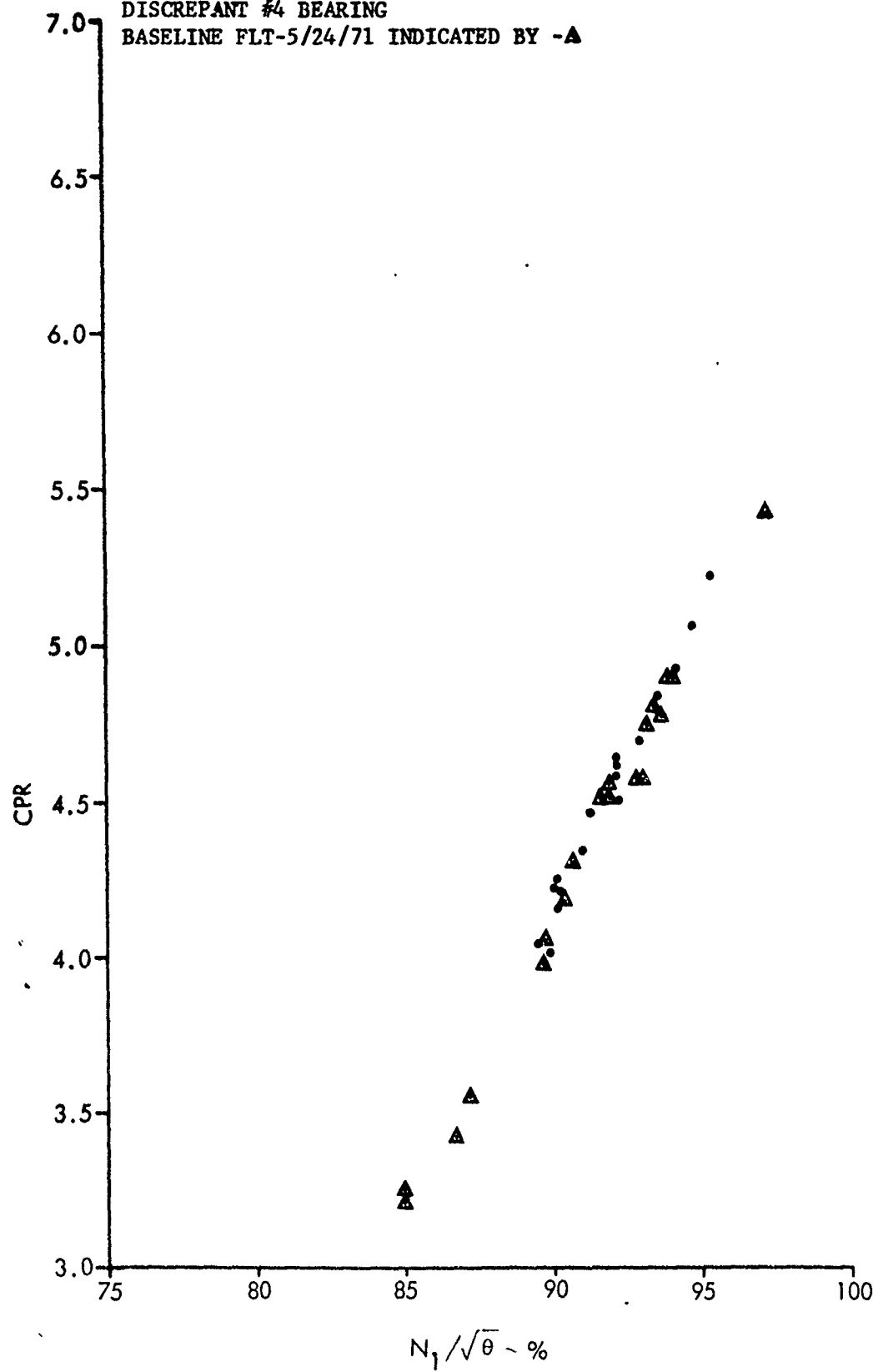


FIGURE 7-73 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

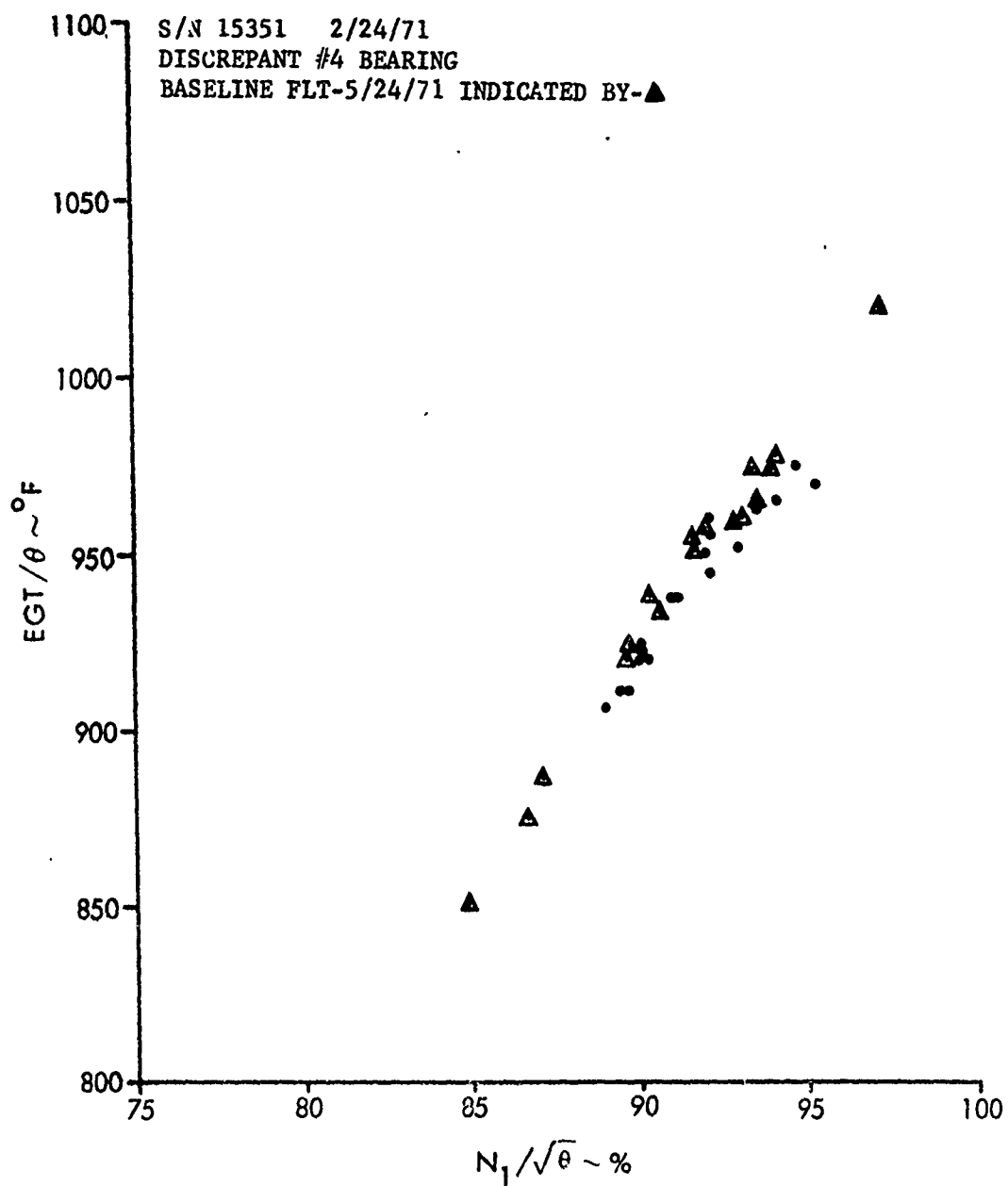


FIGURE 7-74 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

ENG S/N 15351 2/24/71

DISCREPANT #4 BEARING

BASELINE FLT-5/24/71 INDICATED BY -  $\Delta$

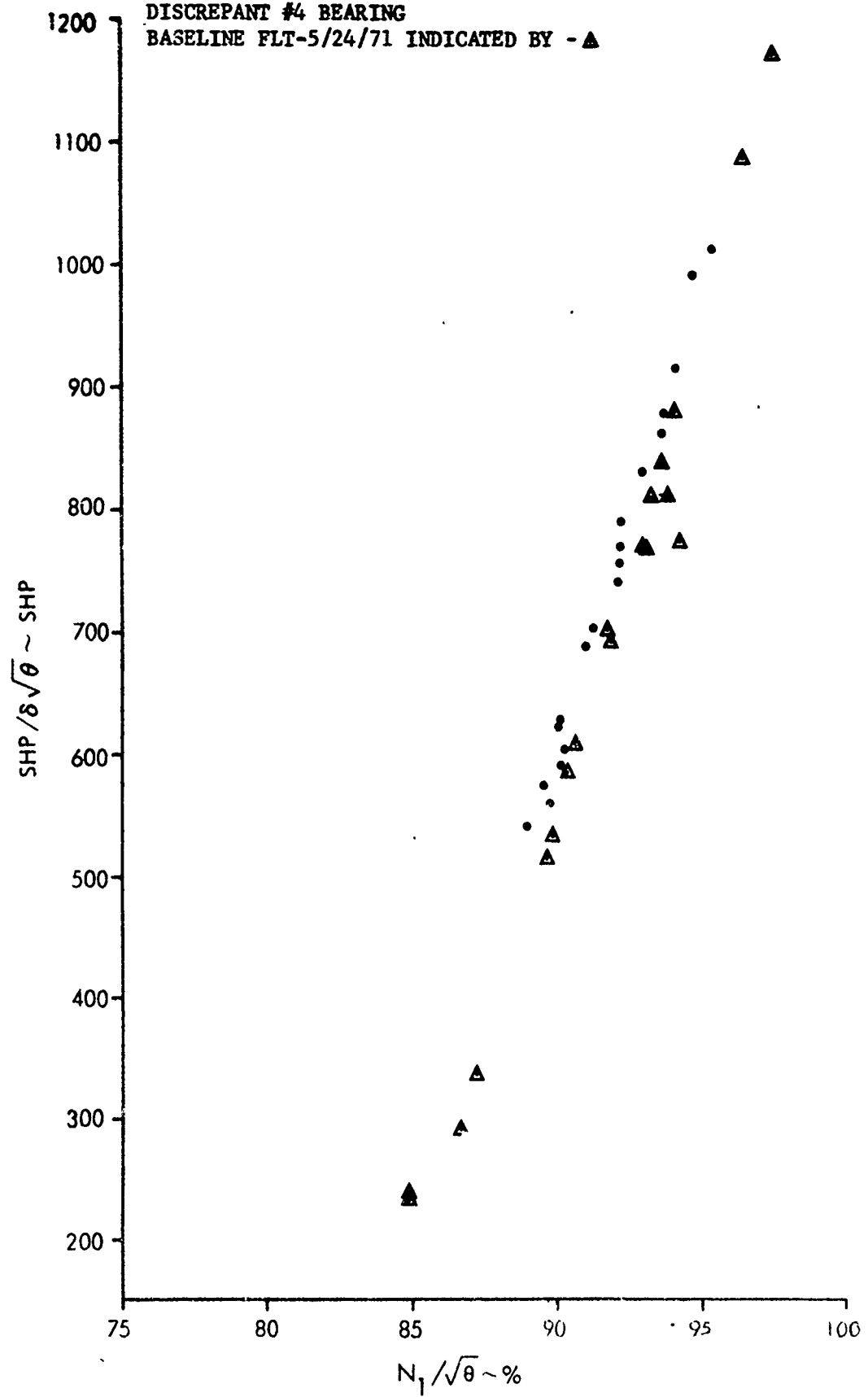


FIGURE 7-75 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

SN15351 3/3/71

DISCREPANT #4 BEARING

BASELINE FLT-5/24/71 INDICATED BY -▲

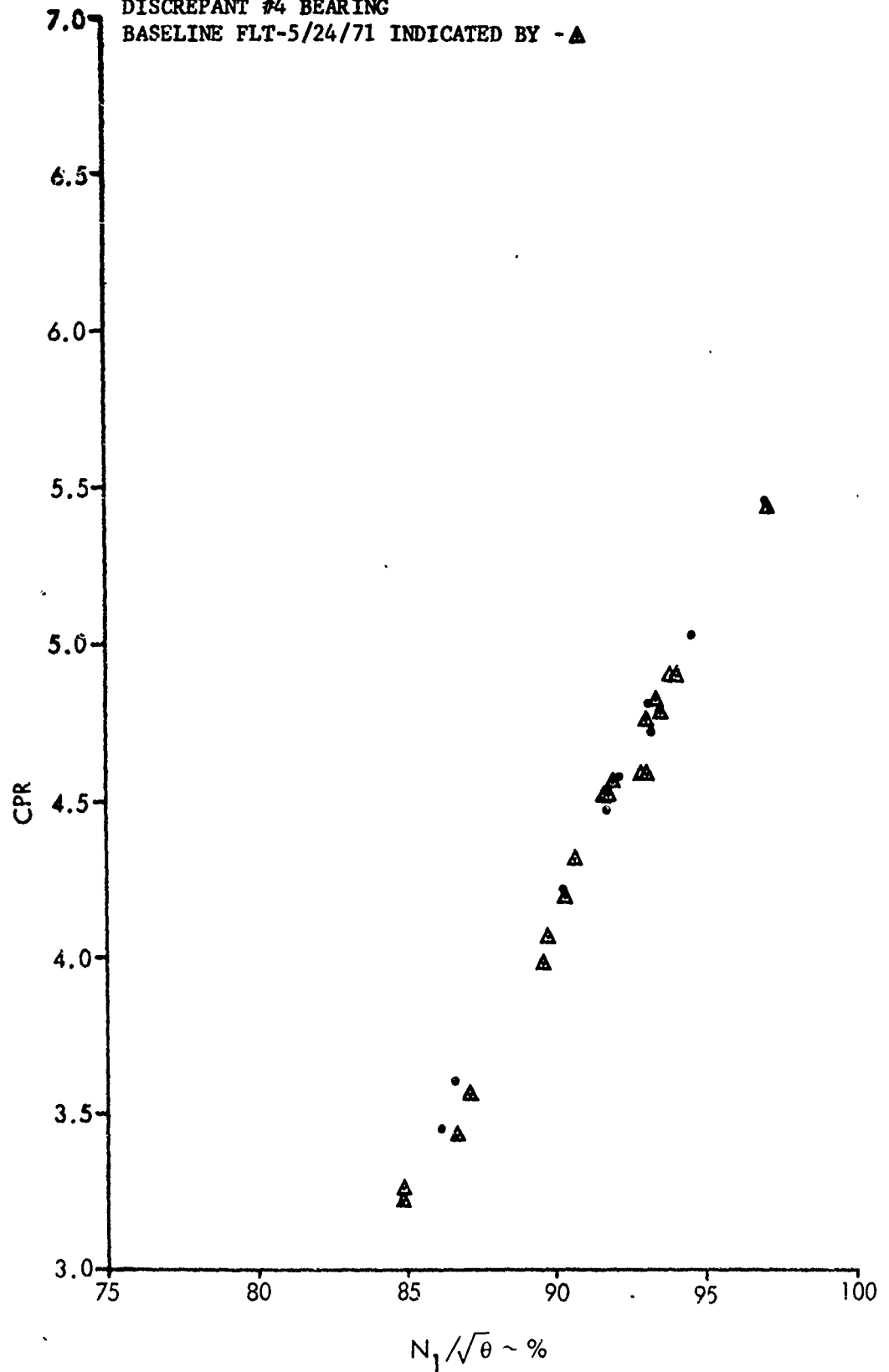


FIGURE 7-76 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

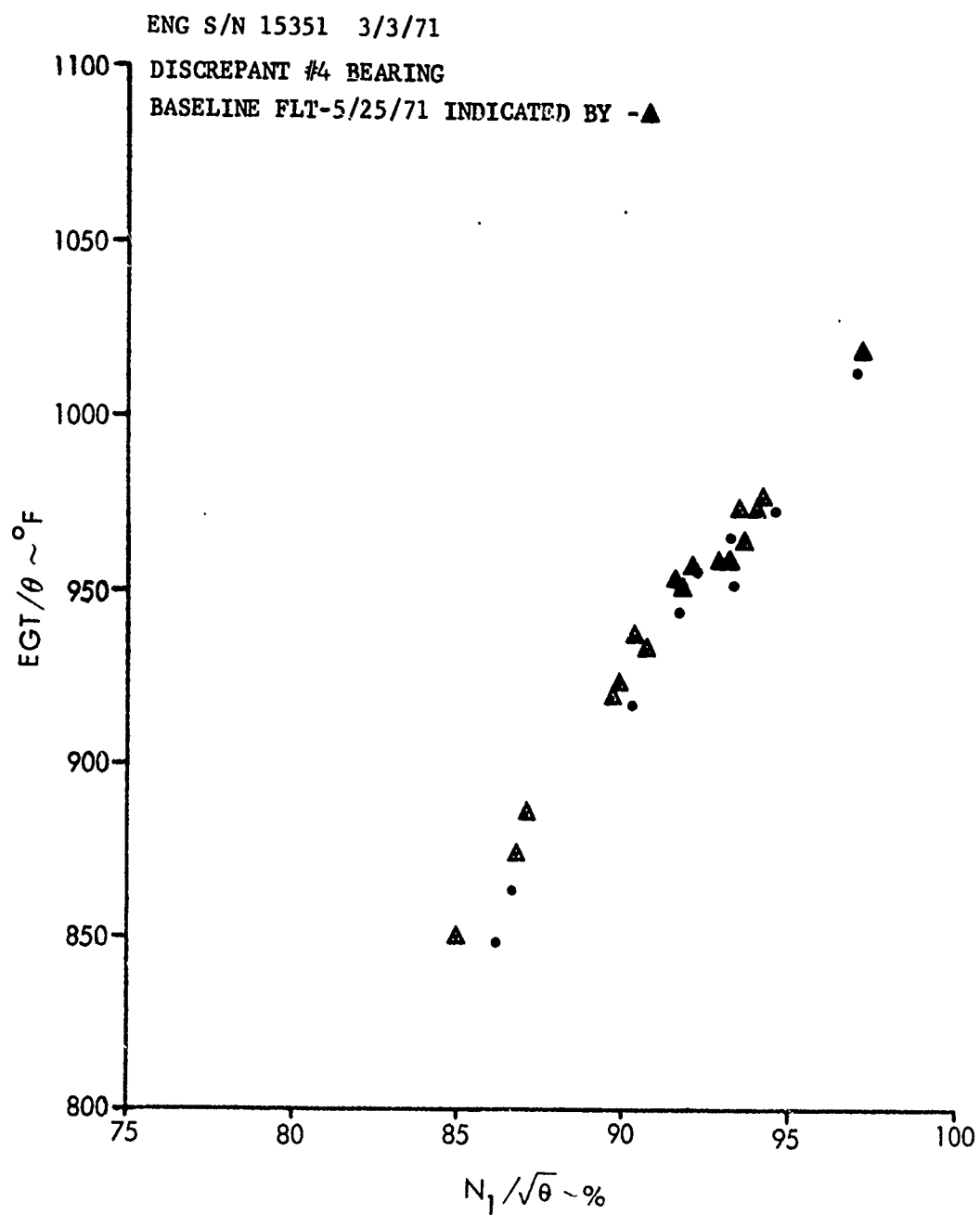


FIGURE 7-77 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

ENG S/N 15351 3/3/71

DISCREPANT #4 BEARING

BASELINE FLT-5/24/71 INDICATED BY -▲

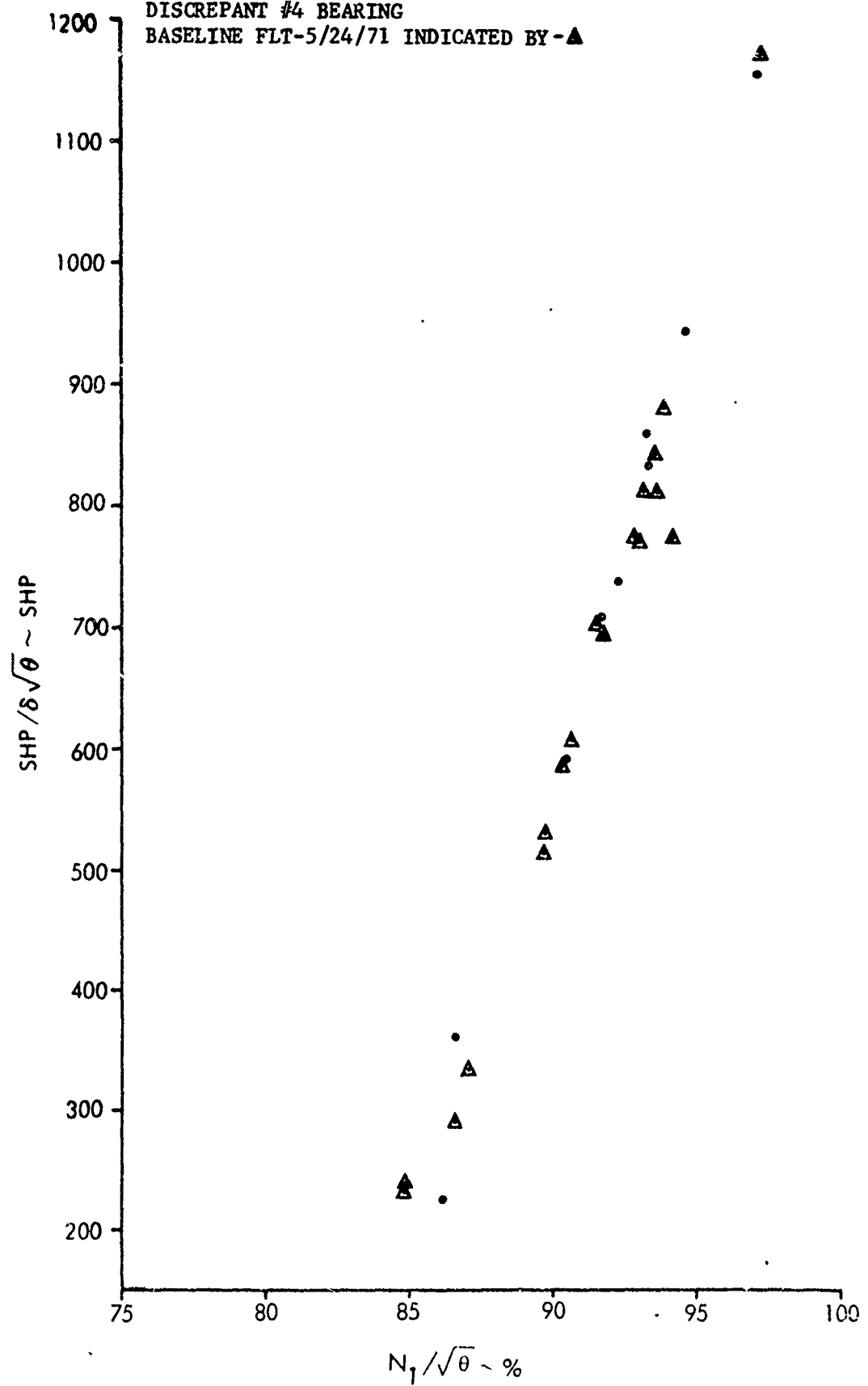


FIGURE 7-78 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

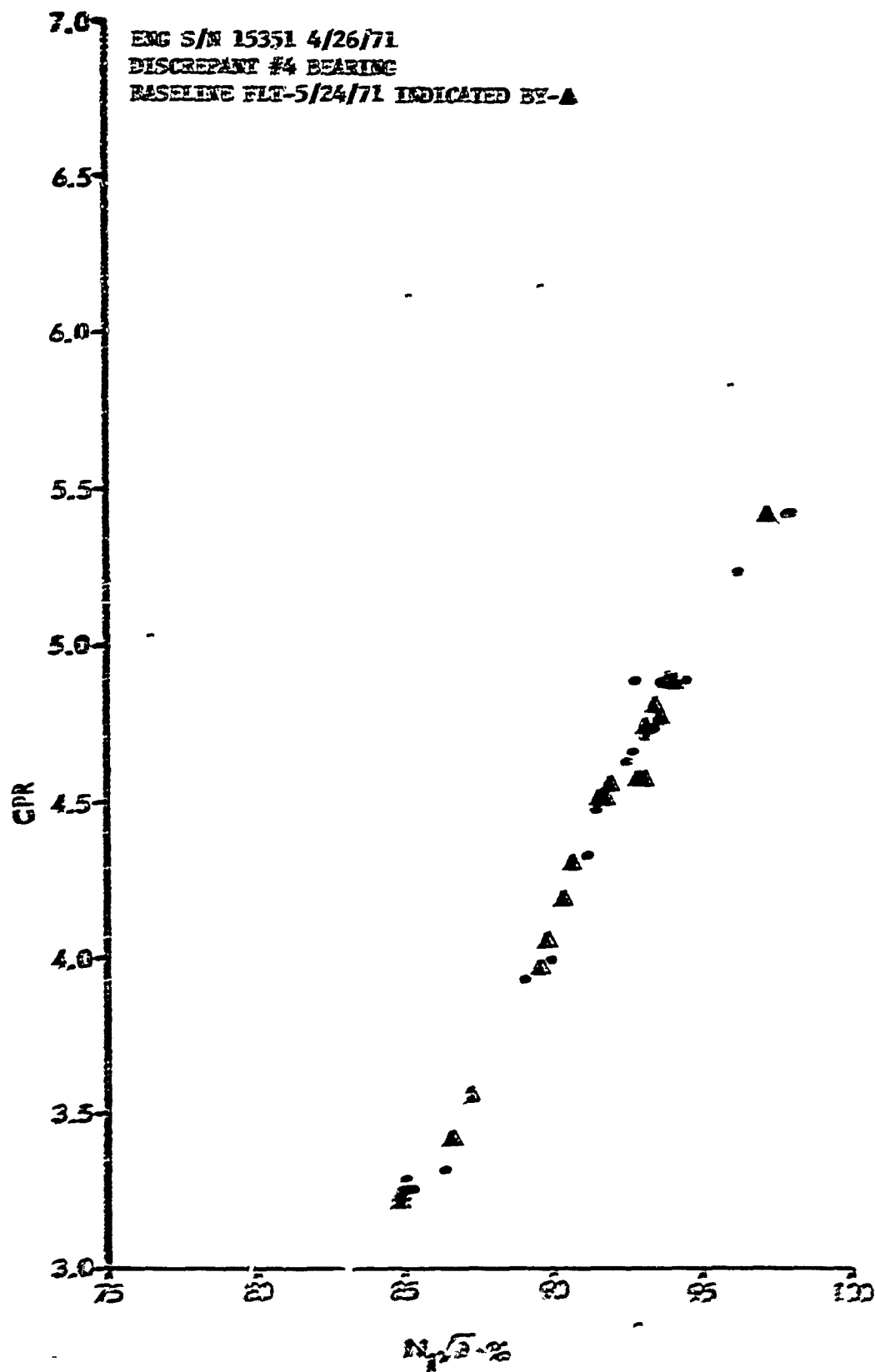


FIGURE 7-79 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

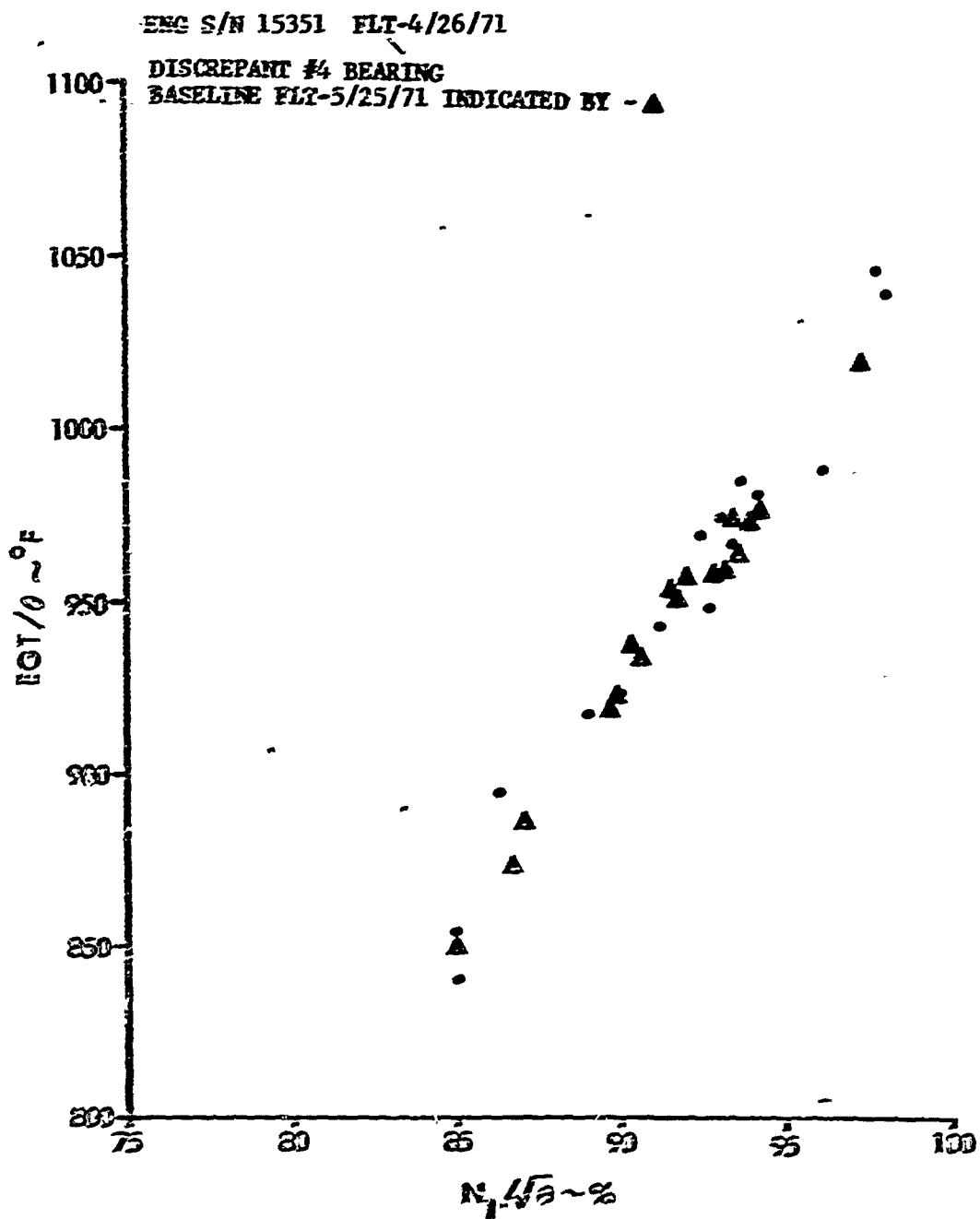


FIGURE 7-20 DISCREPANT BEARING EGT/θ vs N<sub>1</sub>√θ

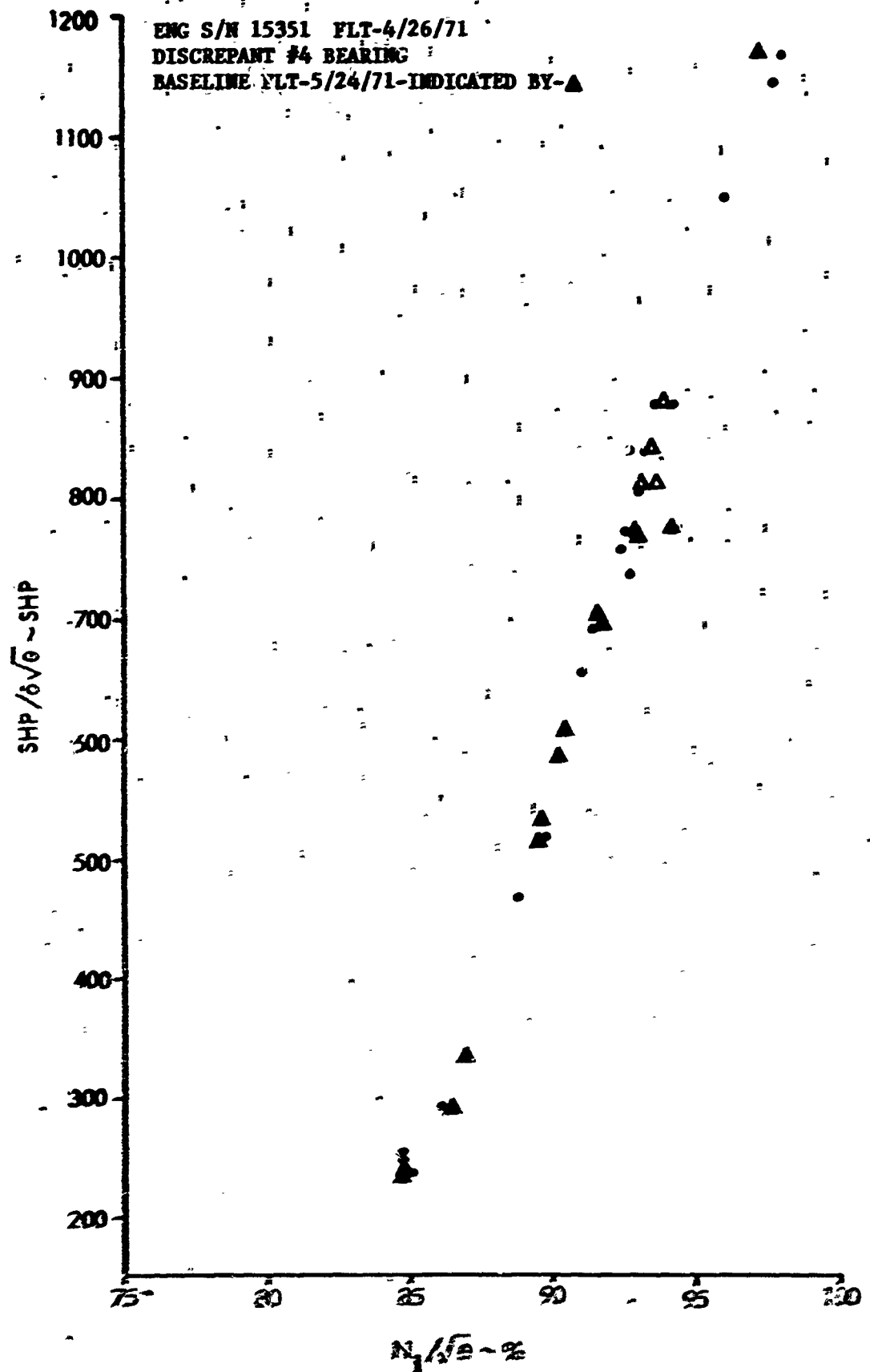


FIGURE 7-81 CORRECTED SHAFT HORSEPOWER VS CORRECTED N. SPEED

ENG S/N 15351 6/14/71

DISCREPANT POWER TURBINE

BASELINE FLT-5/24/71 INDICATED BY -▲

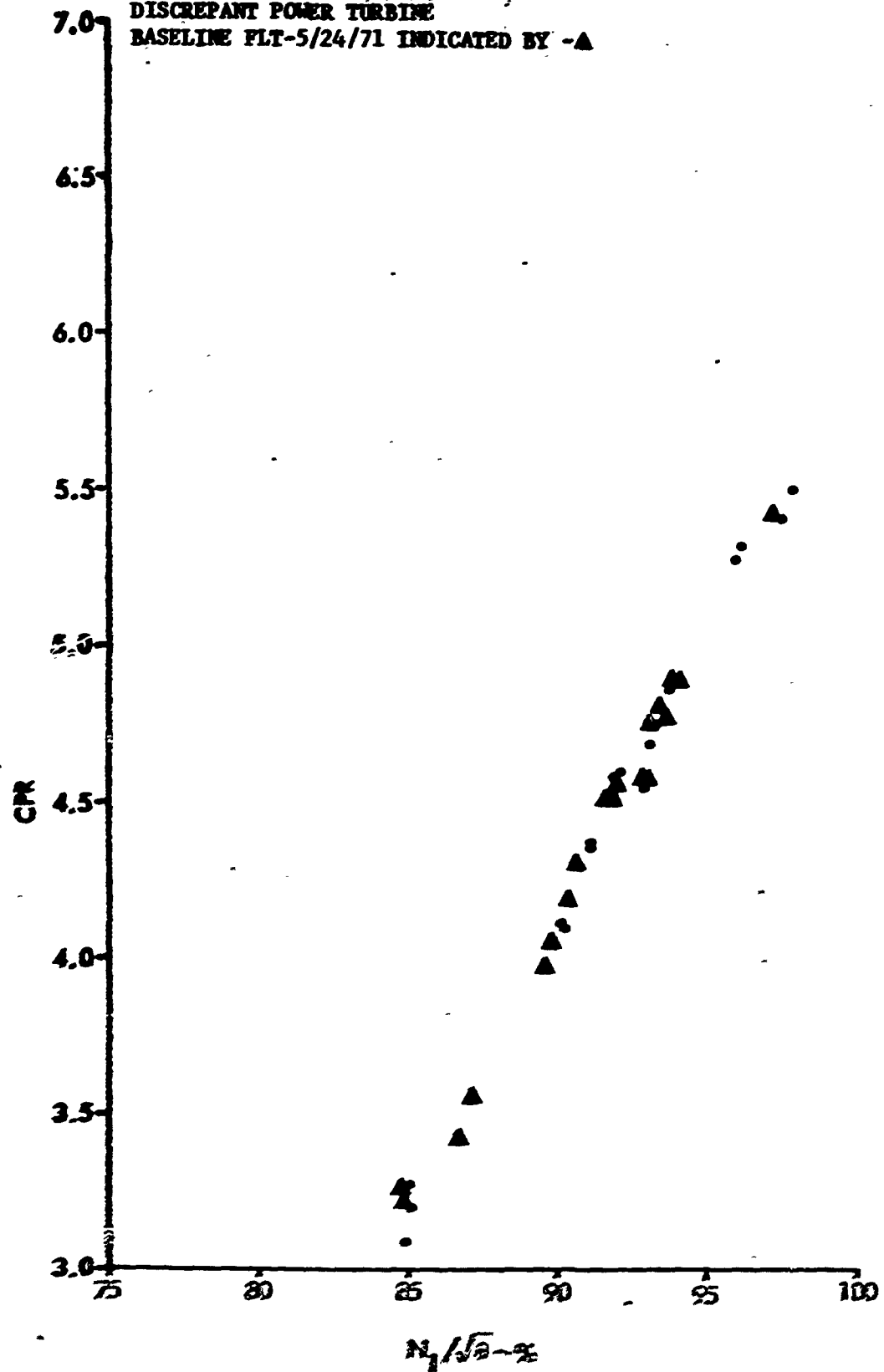


FIGURE 7-24 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

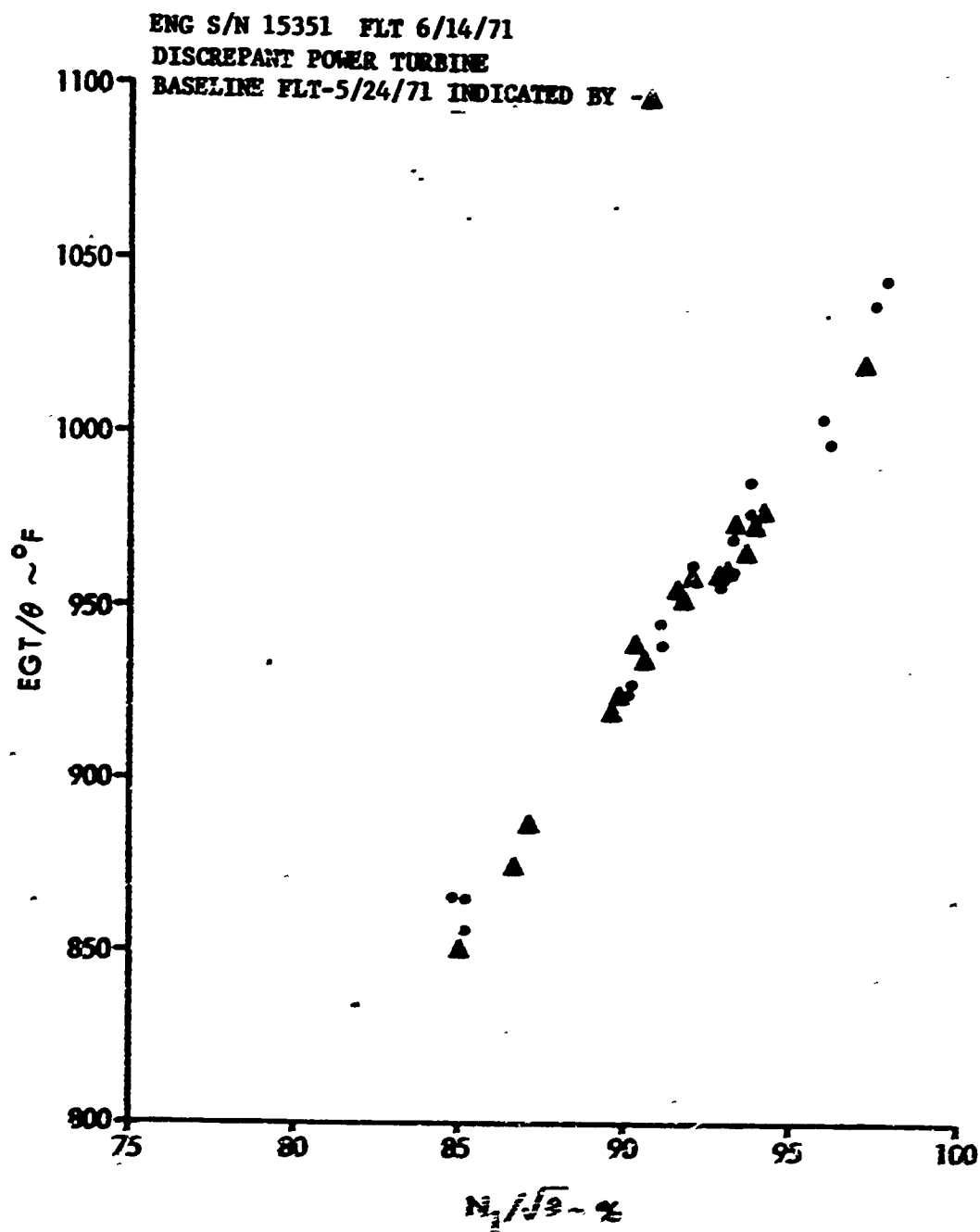


FIGURE 7-83 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED N<sub>1</sub> SPEED

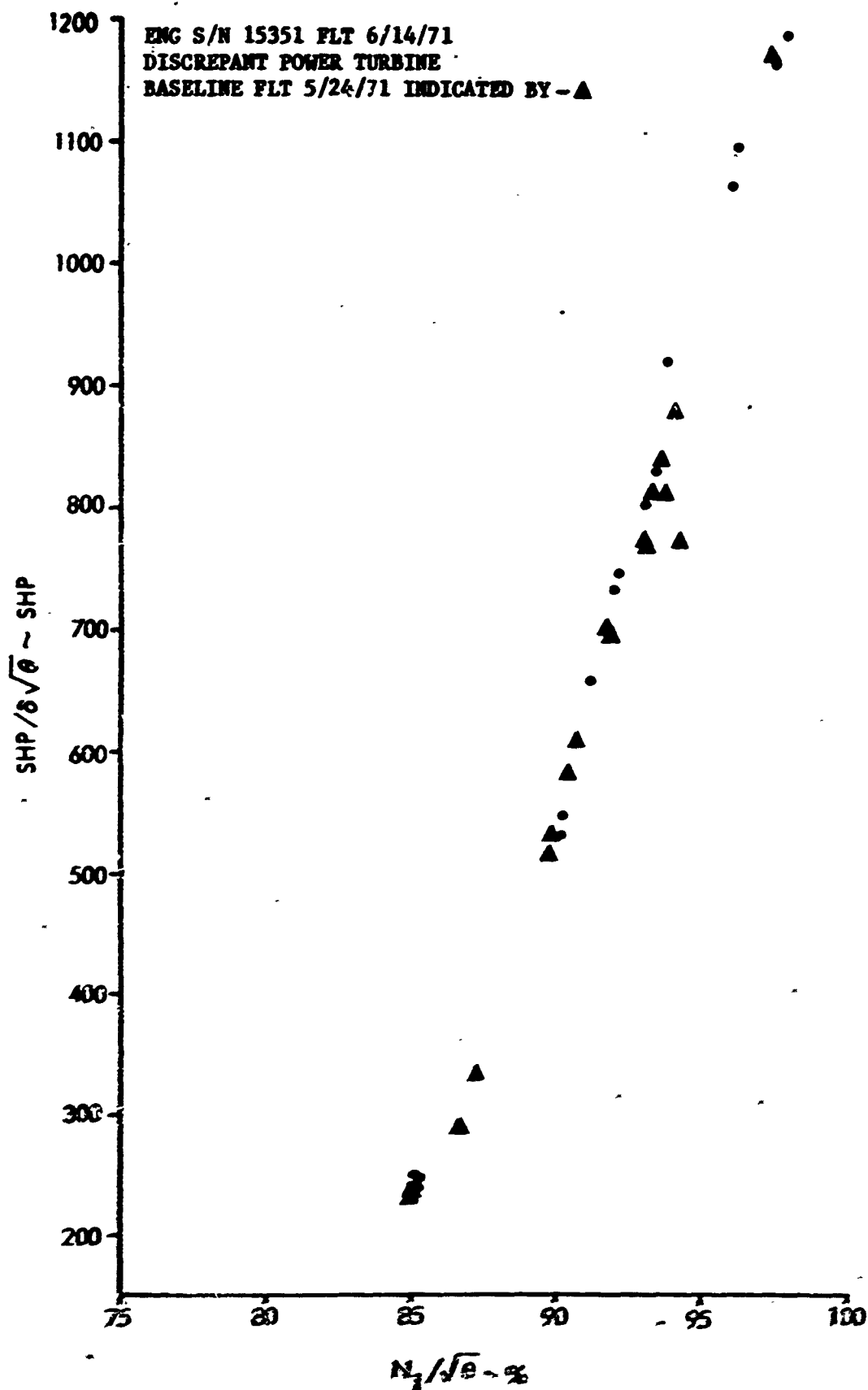


FIGURE 7-24 CORRECTED SHIP HORSPOWER VS CORRECTED  $N_1$  SPEED

ENG S/N 18993 FLT 2/26/71

DISCREPANT  $N_1$  NOZZLES

BASLINE FLT-5/17/71 INDICATED BY -▲

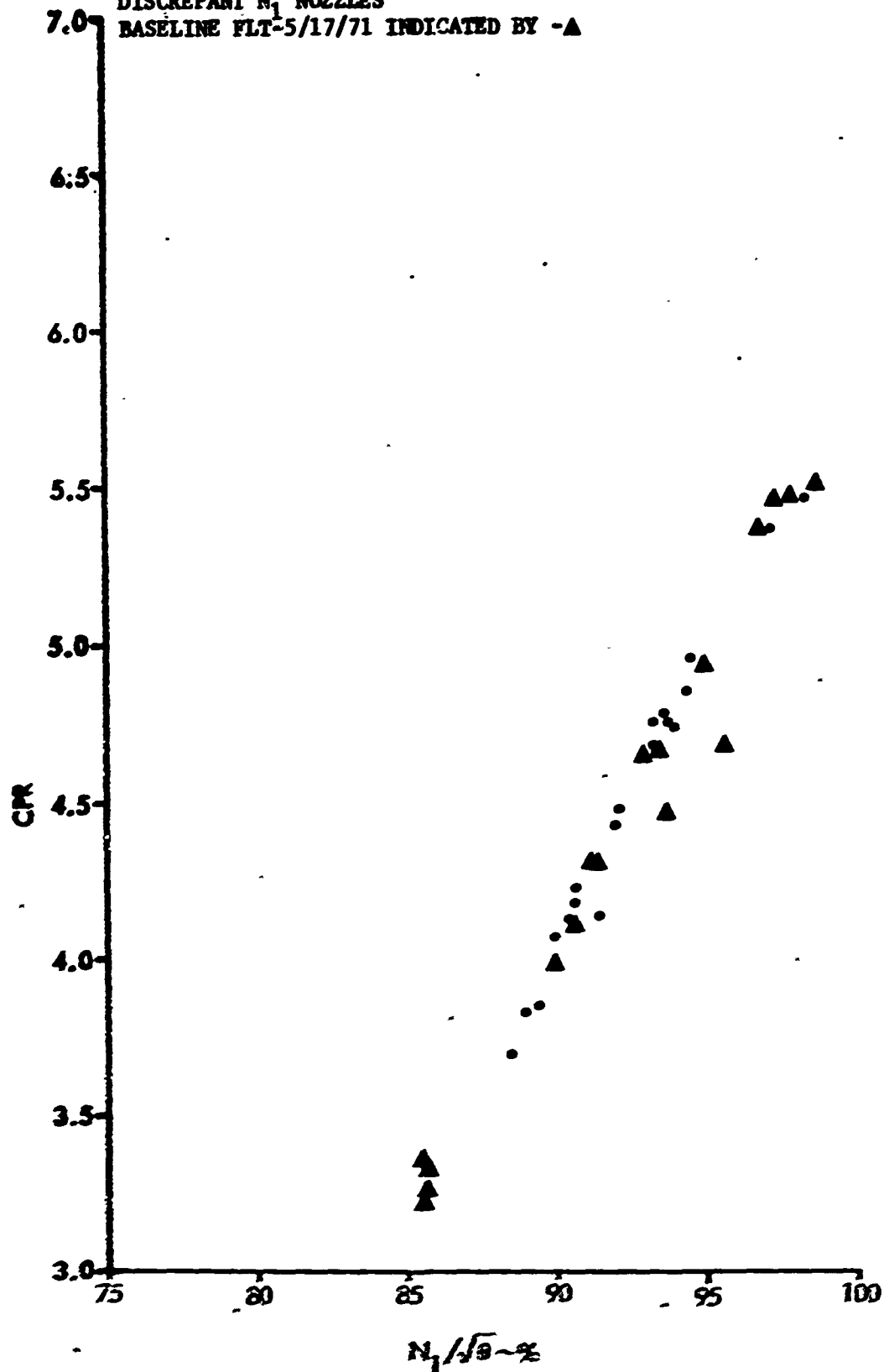


FIGURE 7-85 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

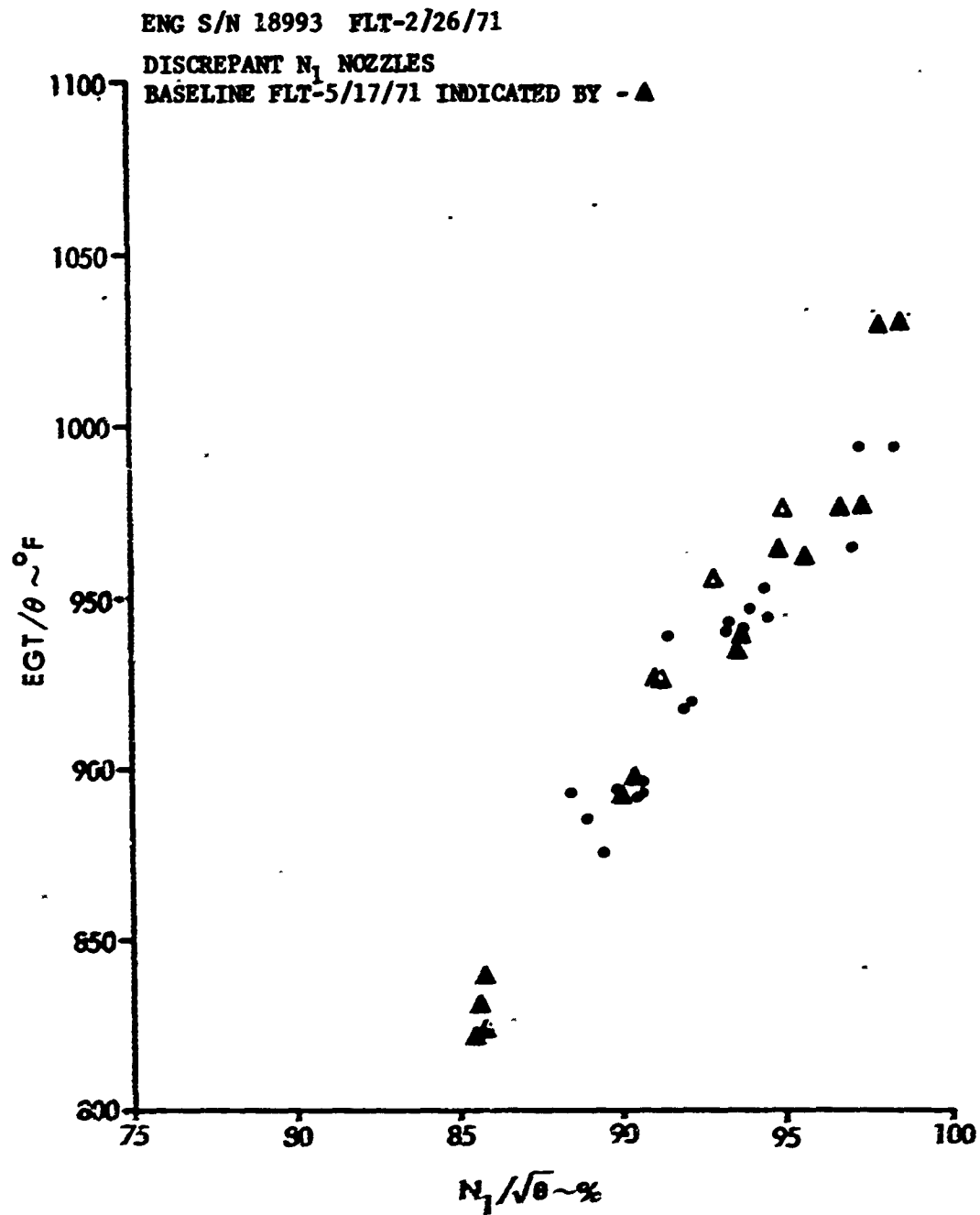


FIGURE 7-36 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

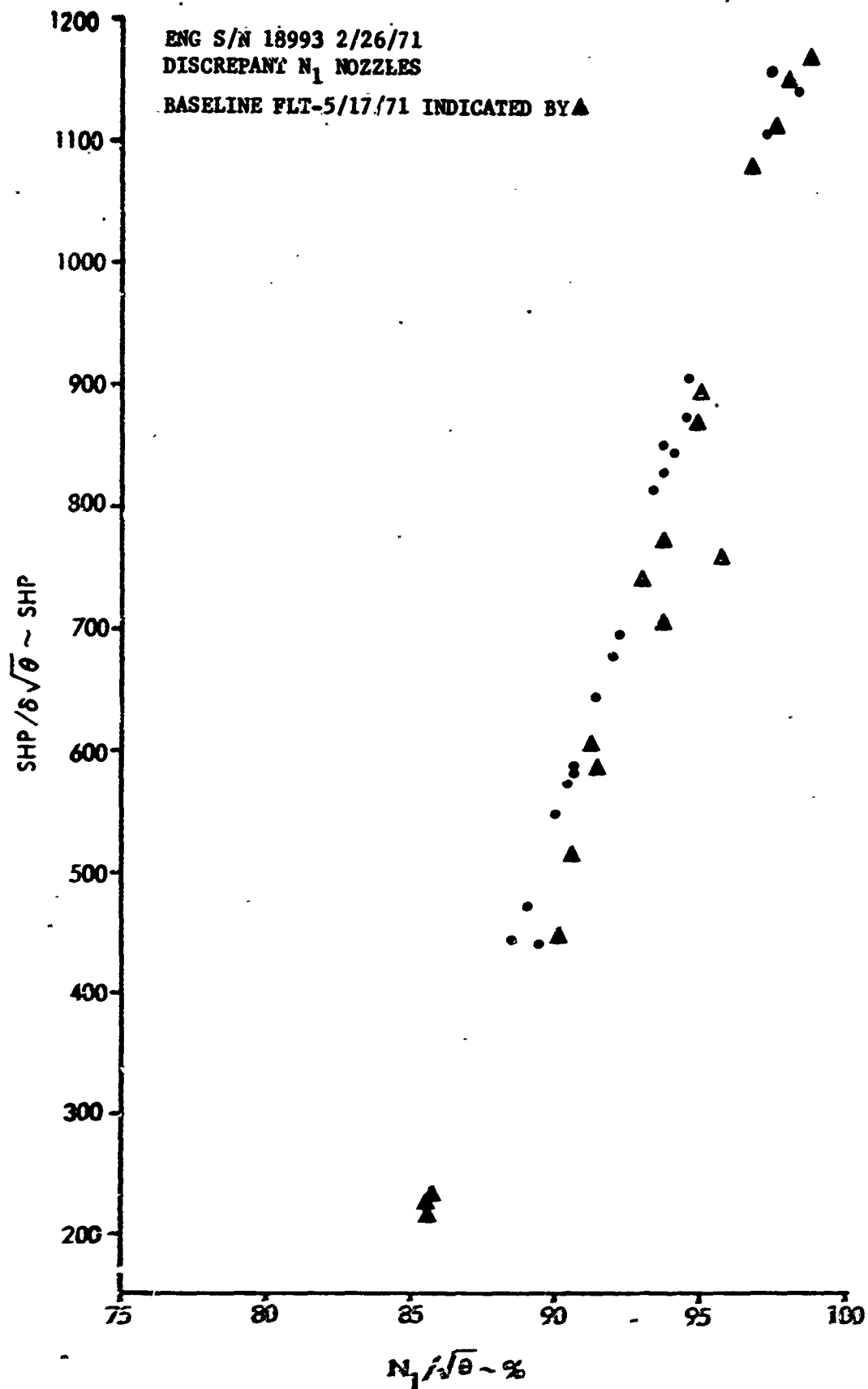


FIGURE 7-67 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

- b) Figures 7-88 through 7-90 show the expected performance degradation for the discrepant  $N_2$  nozzles; normal compressor performance, higher EGT, and increased shaft horsepower. These results indicate that the  $N_2$  nozzle area was larger than normal and caused an increase in the engine mass flow. Higher EGT values probably resulted from higher engine fuel flow. Unfortunately, the engine fuel flow was not recorded during the baseline flight to verify the possible increase in engine fuel flow. However, an evaluation of the engine calculator outputs (KEF) verifies that the fuel flow was higher for the discrepant engine compared to the baseline value.
- c) A classic example of a damaged compressor section was observed on the discrepant engine flight test of 10 June. A discrepant compressor was substantiated by excessive reduction in compressor pressure ratio, increased EGT, and loss in engine shaft horsepower (see figures 7-91 through 7-93). Higher EGT is caused by reduced engine air flow, which increased the fuel-air mixture in the combustion process. An engine power output deficiency resulted from lower engine air flow and pressure.

A test was conducted to determine the effects of a simulated misrigged fuel control unit on engine S/N 18918 performance. During this test, the helicopter was tied down and engine parameters were recorded at two power settings (corrected engine speed of approximately 91.5 and 85 percent). The following fuel control adjustments were made for the test:

- No adjustment
- Half-turn lean
- One-turn lean
- Half-turn rich
- One-turn rich

Figures 7-94 through 7-96 present the effect of the various fuel control adjustments on the engine compressor performance, exhaust gas temperature, and shaft horsepower. Because of technical difficulties encountered during the test, recorded engine fuel flow could not be correlated with the various adjustments made on the fuel control unit and as a result makes it difficult to clearly assess the effect of the fuel control adjustments. However, the following comments can be made from the available engine performance data:

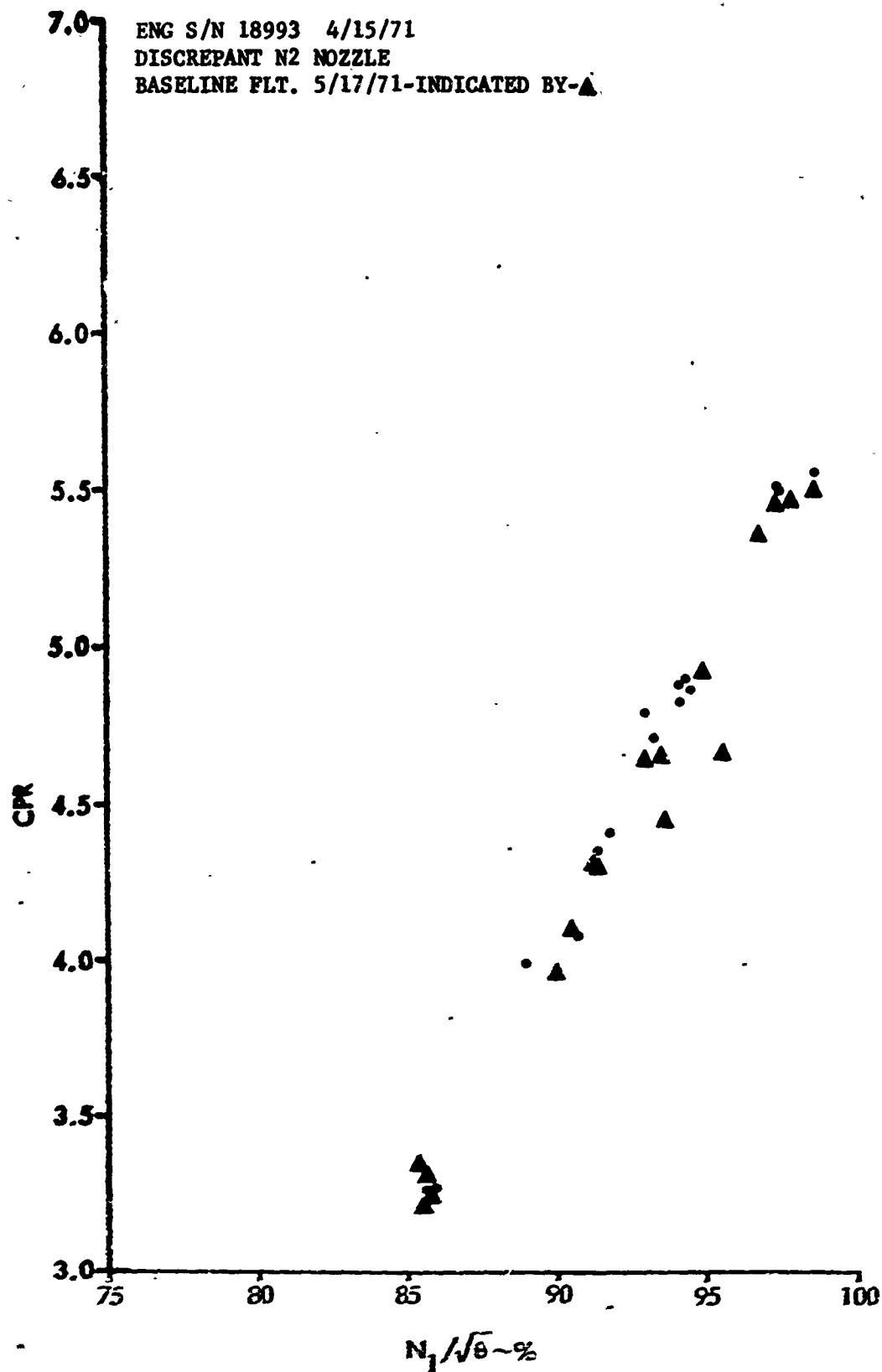


FIGURE 7-88 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

ENG S/N 18993 4/15/71

DISCREPANT N2 NOZZLE

BASLINE FLT 5/17/71-INDICATED BY -▲

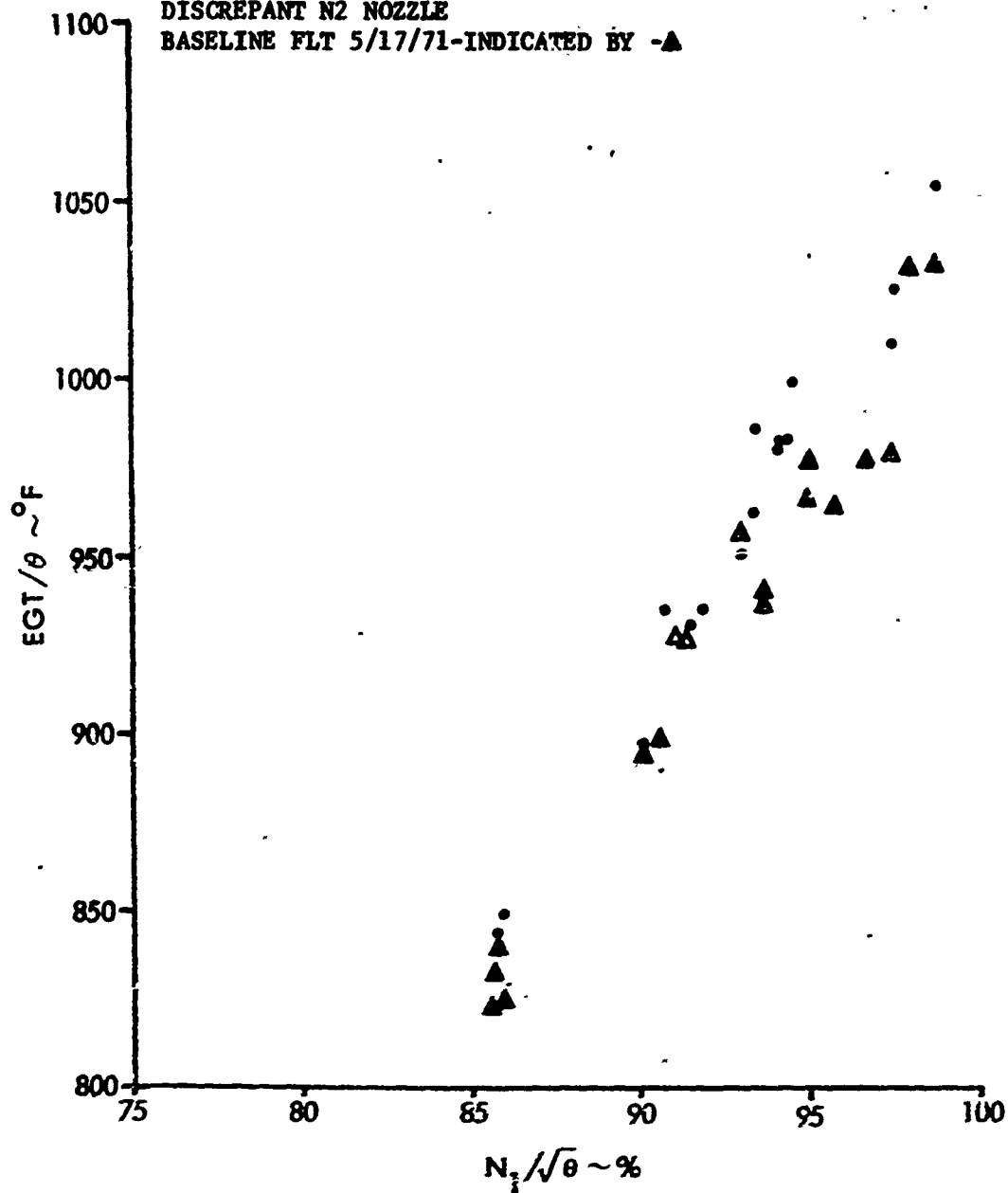


FIGURE 7-89 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED N<sub>1</sub> SPEED

ENG S/N 18993 4/15/71

DISCREPANT N<sub>2</sub> NOZZLE  
BASELINE FLT 5/17/71-INDICATED BY -▲

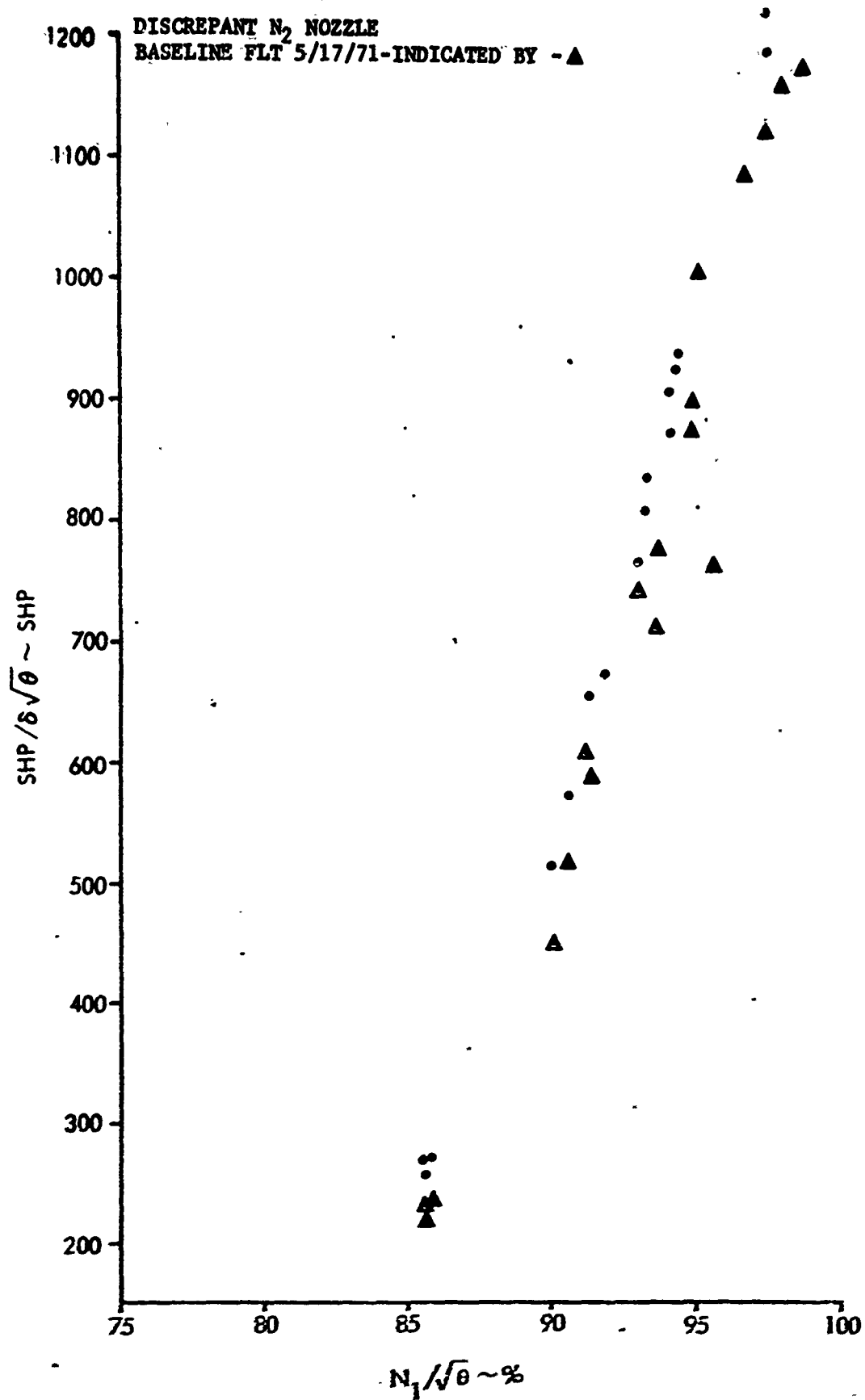


FIGURE 7-90 CORRECTED SHAFT HORSEPOWER VS CORRECTED N<sub>1</sub> SPEED

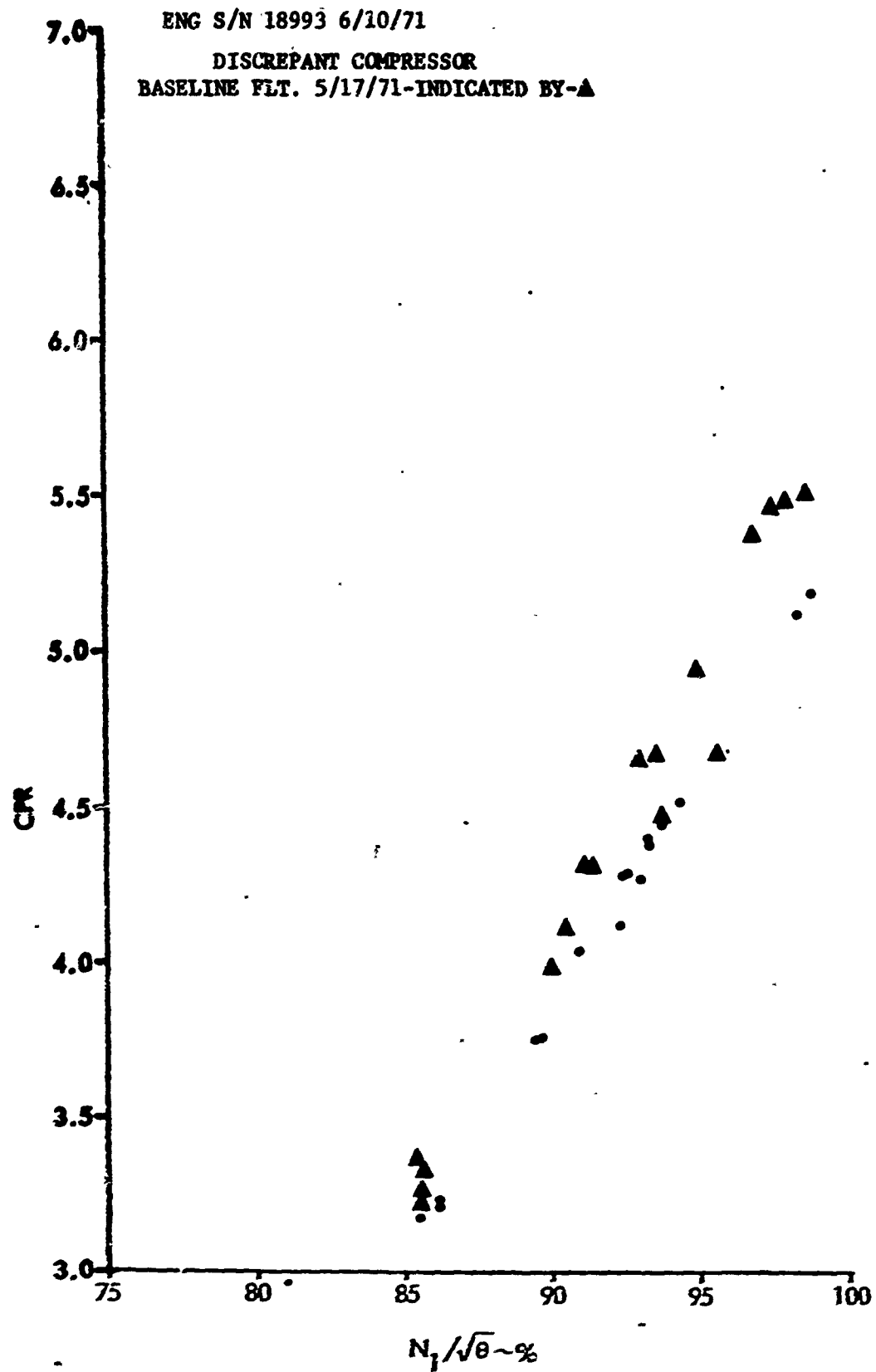


FIGURE 7-91 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

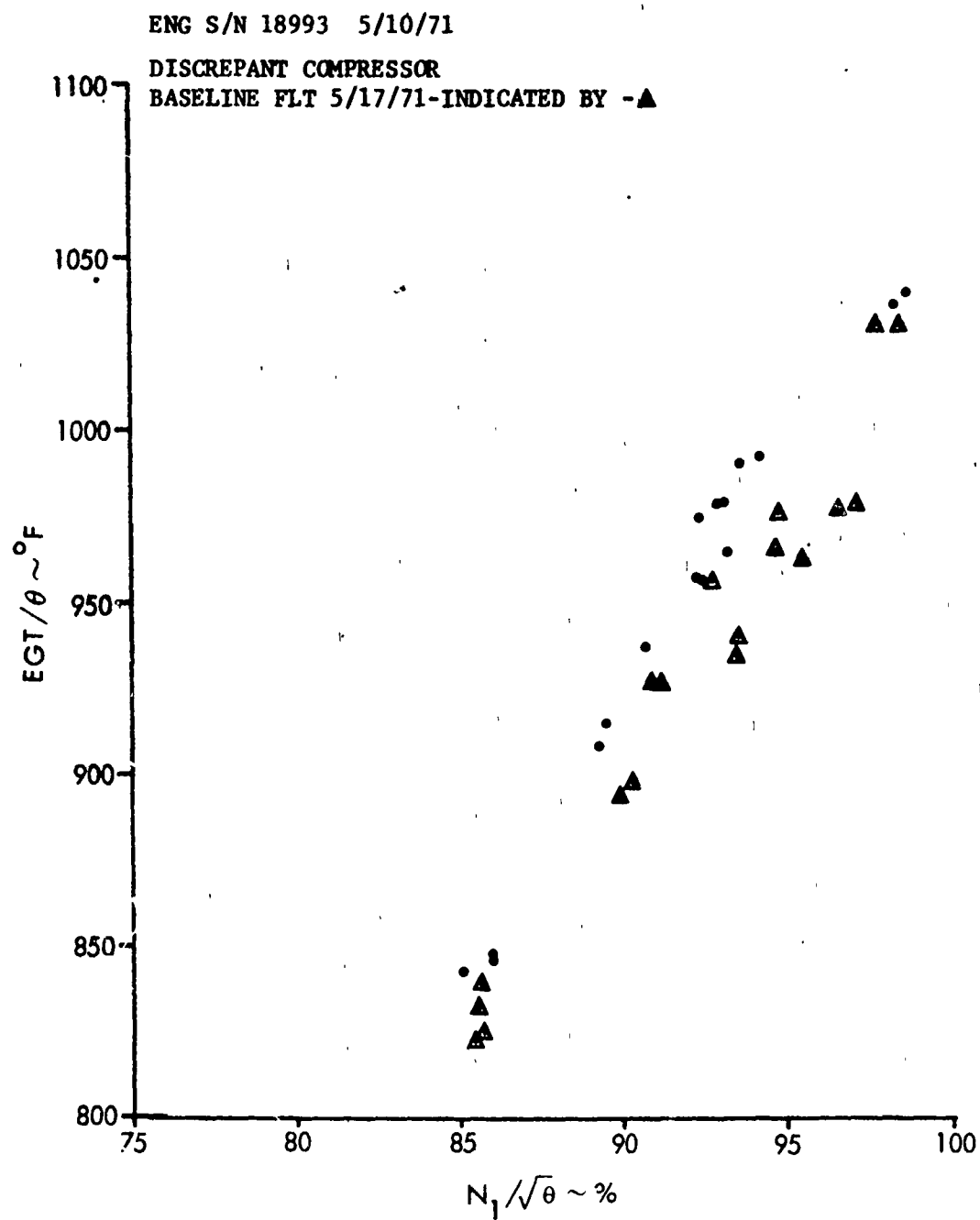


FIGURE 7-92 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

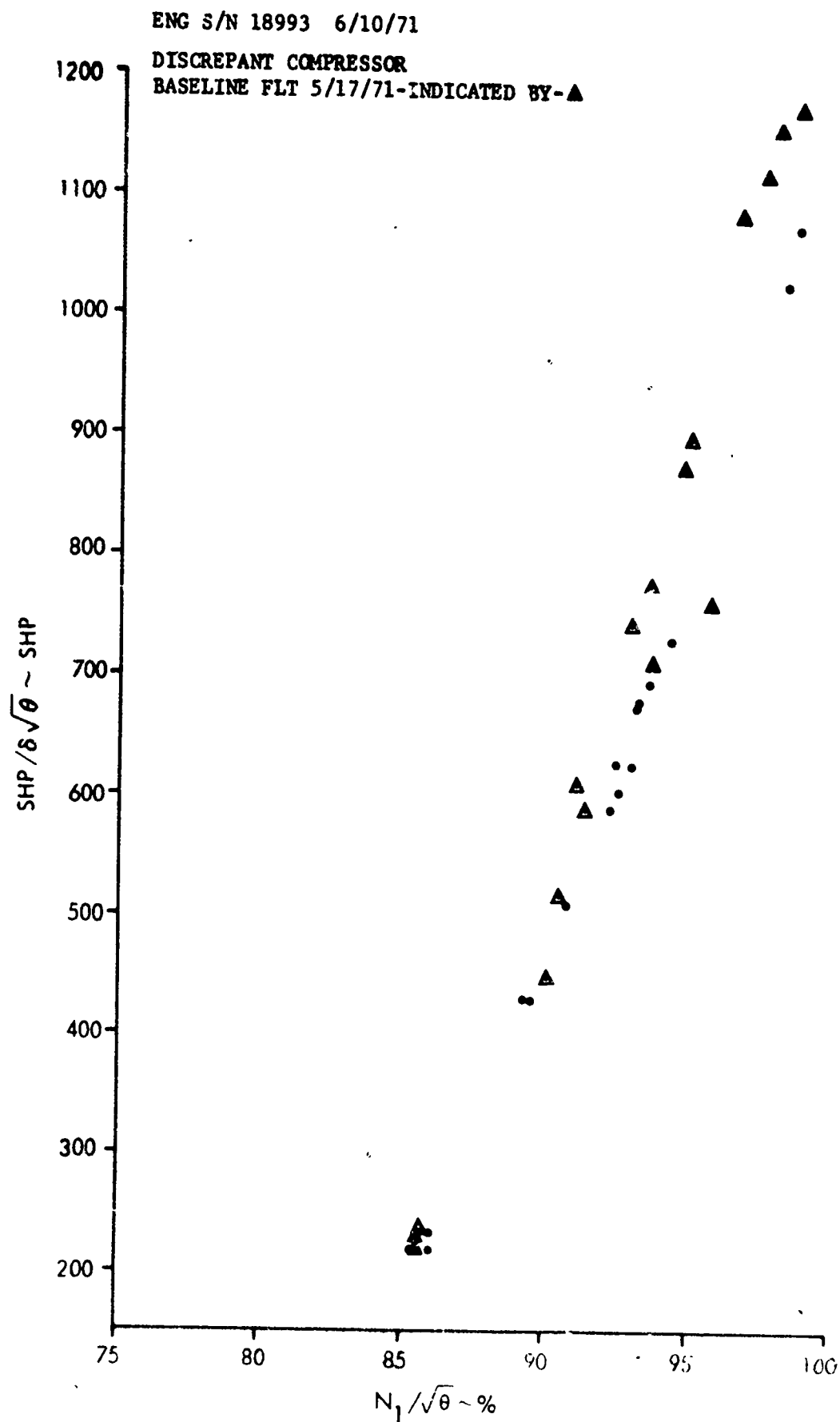


FIGURE 7-93 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

S/N 18918 6/29/71  
 FUEL GOVERNOR TEST  
 A/C TIED DOWN

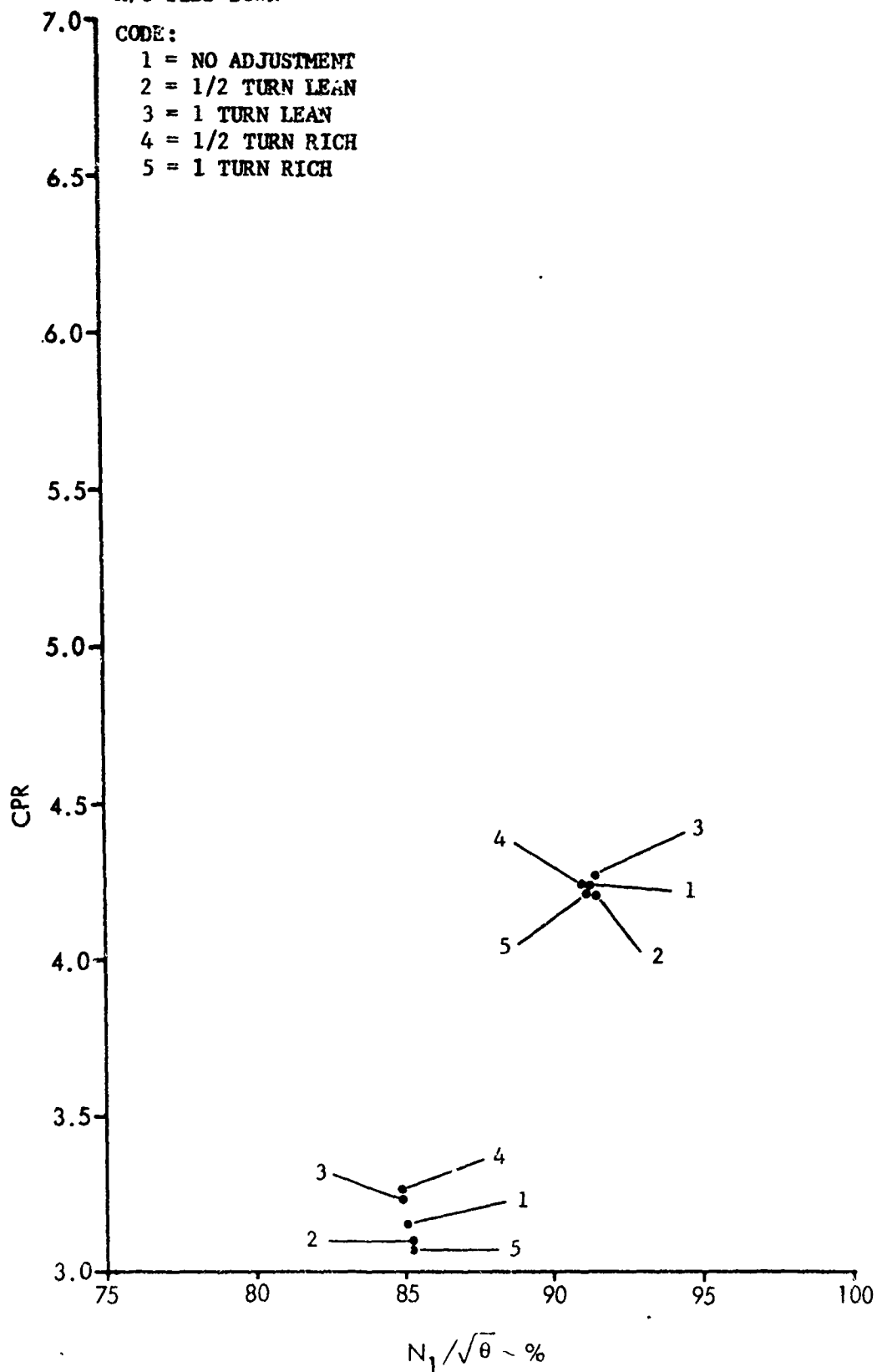


FIGURE 7-94 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

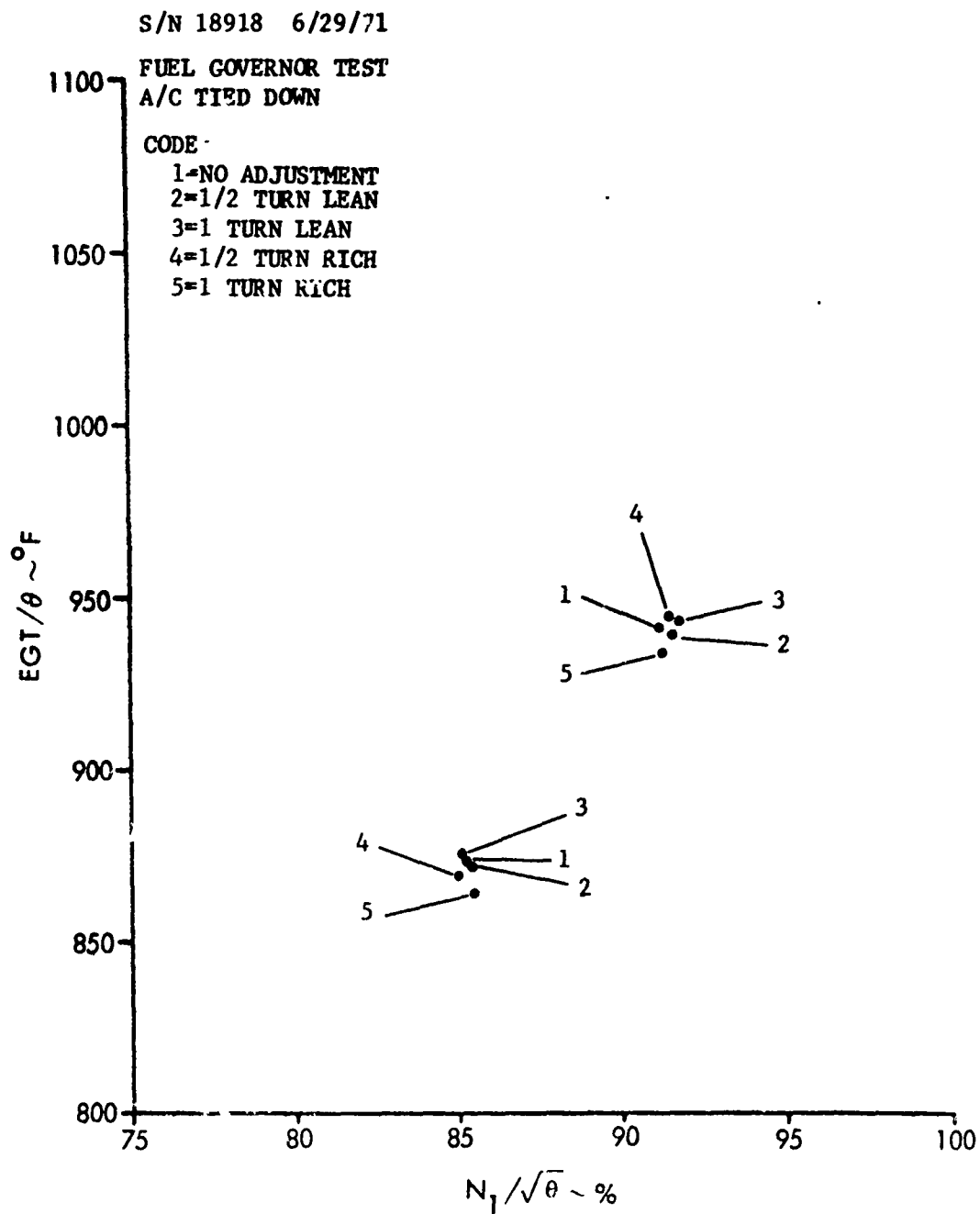


FIGURE 7-95 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

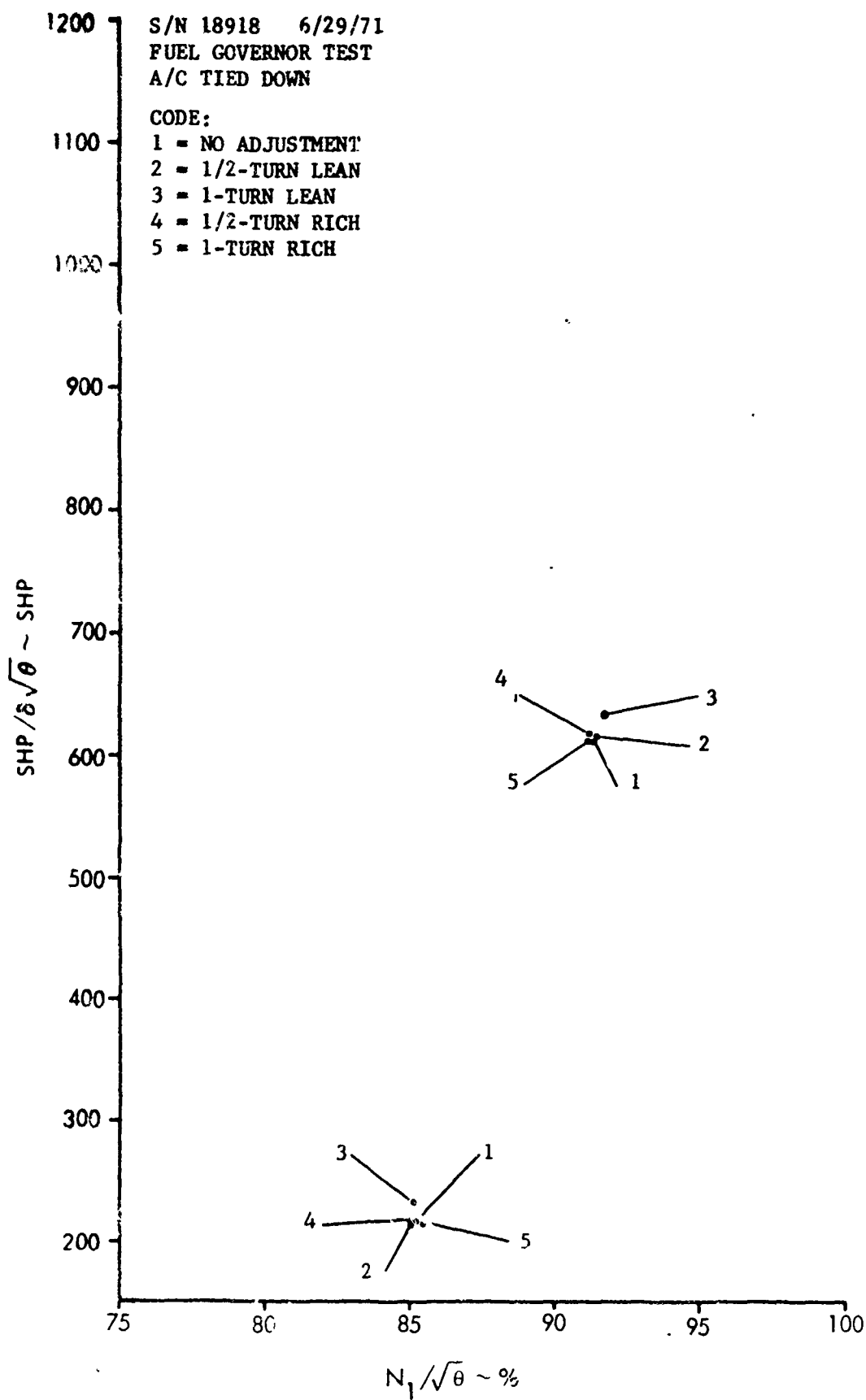


FIGURE 7-96 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

TABLE 7.9A SUMMARY OF DISCREPANT PARTS TESTS, ENGINES

ENGINE S/N	DATE OF FLIGHT	DISCREPANT PART	CPR vs $N_1/\sqrt{\theta}$	EGT/ $\theta$ vs $N_1/\sqrt{\theta}$	$W_p/\sqrt{\theta}$ vs $N_1/\sqrt{\theta}$	SHP/ $\sqrt{\theta}$ vs $N_1/\sqrt{\theta}$	SHP/ $\sqrt{\theta}$ vs $W_p/\sqrt{\theta}$	EGT/ $\theta$ vs $W_p/\sqrt{\theta}$	EGT/ $\theta$ vs SHP/ $\sqrt{\theta}$
20727	2-19-71	No. 3 Bearing	No Effect	No Effect	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Lower ( $>2\%$ , $<10\%$ )
	3-19-71	Power Turbine	No Effect	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ ) at High SHP
	6-3-71	No. 3 Bearing	No Effect	No Effect	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Lower ( $>2\%$ , $<10\%$ )
	6-21-71	$N_2$ Nozzles	No Effect	No Effect	No $W_p$ Taken	Slightly Higher ( $<2\%$ )	No $W_p$ Taken	No $W_p$ Taken	Slightly Lower ( $<2\%$ )
18993	2-16-71	$N_1$ Nozzles	Slightly Higher ( $<2\%$ )	Slightly Lower ( $<2\%$ )	No $W_p$ Taken	Slightly Higher ( $<2\%$ )	No $W_p$ Taken	No $W_p$ Taken	Lower ( $>2\%$ , $<10\%$ )
	4-15-71	$N_2$ Nozzles	No Effect	Higher ( $>2\%$ , $<10\%$ )	No $W_p$ Taken	Higher ( $>2\%$ , $<10\%$ )	No $W_p$ Taken	No $W_p$ Taken	No Effect
	6-10-71	FOD	Lower ( $>2\%$ , $<10\%$ )	Higher ( $>2\%$ , $<10\%$ )	No $W_p$ Taken	Lower ( $>2\%$ , $<10\%$ )	No $W_p$ Taken	No $W_p$ Taken	Higher ( $>2\%$ , $<10\%$ )
	3-11-71	FOD	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Slightly Higher ( $<2\%$ )
15615	5-27-71	No. 2 Nozzles	No Effect	No Effect	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	No Effect
	6-17-71	$N_1$ Nozzles	No Effect	No Effect	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Slightly Lower ( $<2\%$ )
	2-24-71	No. 4 Bearing	No Effect	Slightly Lower ( $<2\%$ )	No $W_p$ Taken	Slightly Higher ( $<2\%$ )	No $W_p$ Taken	No $W_p$ Taken	Lower ( $>2\%$ , $<10\%$ )
	3-3-71	No. 4 Bearing	No Effect	Slightly Lower ( $<2\%$ )	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Lower ( $>2\%$ , $<10\%$ )
15351	4-26-71	No. 4 Bearing	No Effect	No Effect	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Slightly Higher ( $<2\%$ )
	6-14-71	Power Turbine	No Effect	No Effect	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Slightly Lower ( $<2\%$ ) at High SHP

TABLE 7.9A SUMMARY OF DISCREPANT PARTS TESTS, ENGINES

ENGINE S/N	DATE OF FLIGHT	DISCREPANT PART	CPR vs $N_1/\sqrt{\theta}$	EGT/ $\theta$ vs $N_1/\sqrt{\theta}$	$W_p/\sqrt{\theta}$ vs $N_1/\sqrt{\theta}$	SHP/ $\sqrt{\theta}$ vs $N_1/\sqrt{\theta}$	SHP/ $\sqrt{\theta}$ vs $W_p/\sqrt{\theta}$	EGT/ $\theta$ vs $W_p/\sqrt{\theta}$	EGT/ $\theta$ vs SHP/ $\sqrt{\theta}$
20727	2-19-71	No. 3 Bearing	No Effect	No Effect	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Lower ( $>2\%$ , $<10\%$ )
	3-19-71	Power Turbine	No Effect	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ ) at High SHP
	6-3-71	No. 3 Bearing	No Effect	No Effect	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Lower ( $>2\%$ , $<10\%$ )
	6-21-71	$N_2$ Nozzles	No Effect	No Effect	No $W_p$ Taken	Slightly Higher ( $<2\%$ )	No $W_p$ Taken	No $W_p$ Taken	Slightly Lower ( $<2\%$ )
18993	2-16-71	$N_1$ Nozzles	Slightly Higher ( $<2\%$ )	Slightly Lower ( $<2\%$ )	No $W_p$ Taken	Slightly Higher ( $<2\%$ )	No $W_p$ Taken	No $W_p$ Taken	Lower ( $>2\%$ , $<10\%$ )
	4-15-71	$N_2$ Nozzles	No Effect	Higher ( $>2\%$ , $<10\%$ )	No $W_p$ Taken	Higher ( $>2\%$ , $<10\%$ )	No $W_p$ Taken	No $W_p$ Taken	No Effect
	6-10-71	FOD	Lower ( $>2\%$ , $<10\%$ )	Higher ( $>2\%$ , $<10\%$ )	No $W_p$ Taken	Lower ( $>2\%$ , $<10\%$ )	No $W_p$ Taken	No $W_p$ Taken	Higher ( $>2\%$ , $<10\%$ )
	3-11-71	FOD	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Slightly Higher ( $<2\%$ )
15615	5-27-71	No. 2 Bearing	No Effect	No Effect	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	No Effect
	6-17-71	$N_1$ Nozzles	No Effect	No Effect	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Slightly Lower ( $<2\%$ )
	2-24-71	No. 4 Bearing	No Effect	Slightly Lower ( $<2\%$ )	No $W_p$ Taken	Slightly Higher ( $<2\%$ )	No $W_p$ Taken	No $W_p$ Taken	Lower ( $>2\%$ , $<10\%$ )
	3-3-71	No. 4 Bearing	No Effect	Slightly Lower ( $<2\%$ )	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Lower ( $>2\%$ , $<10\%$ )
15351	4-26-71	No. 4 Bearing	No Effect	No Effect	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Slightly Higher ( $<2\%$ )
	6-14-71	Power Turbine	No Effect	No Effect	No $W_p$ Taken	No Effect	No $W_p$ Taken	No $W_p$ Taken	Slightly Lower ( $<2\%$ , $<10\%$ ) at High SHP

- a) Figure 7-94 shows that the compressor performance was not affected by the simulated misrigged fuel control at the higher engine speed (corrected speed of about 91.5 percent). At the lower engine speed of 85 percent, a half-turn rich and one-turn lean on the fuel control unit both increased the compressor pressure ratio. The other two adjustments produced the opposite effect.
- b) Only slight effect on EGT was obtained for a fuel control adjusted to one-turn rich. This position lowered the baseline EGT approximately 10°F.
- c) The only adjustment affecting the engine shaft horsepower was a one-turn lean position, which produced approximately 20 SHP increase at both power settings.
- d) The data indicates that the best engine performance is achieved when the fuel control unit is adjusted one-turn lean. At this position, the EGT is not affected and the other two parameters -- compressor pressure ratio and shaft horsepower -- are improved. It should also have the lowest engine fuel flow.

A comprehensive summary of the results of engine analysis for all flights throughout this period is shown on table 7.9A. Engines are shown by date, discrepant part and effect on gas dynamics relationship.

### 7.7.3 MISCELLANEOUS SYSTEMS MONITORING

#### 7.7.3.1 No. 2 Bearing $\Delta T$

Number 2 bearing differential temperature showed a definite characteristic which varied directly as a function of the power output of the engine (see figures 7-97 through 7-101). The pattern of change is consistent from engine to engine with the peak temperatures and average values varying somewhat. It is apparent that a change in bearing temperature could be detected if the bearing was gradually deteriorating, but inconsistencies result when the engine teardown cycle is considered.

Flight of engine S/N 15615 (27 May 1971) with a bad No. 2 bearing definitely had peak temperatures (both positive and negative peaks) which significantly exceeded the temperatures of the baseline flight (12 May 1971). However, the next flight of the same engine with a good No. 2 bearing and a bad N<sub>1</sub> nozzle had peak temperatures of essentially the same magnitude. Further evaluation of the inconsistency revealed that it was quite probable, as in the case of the

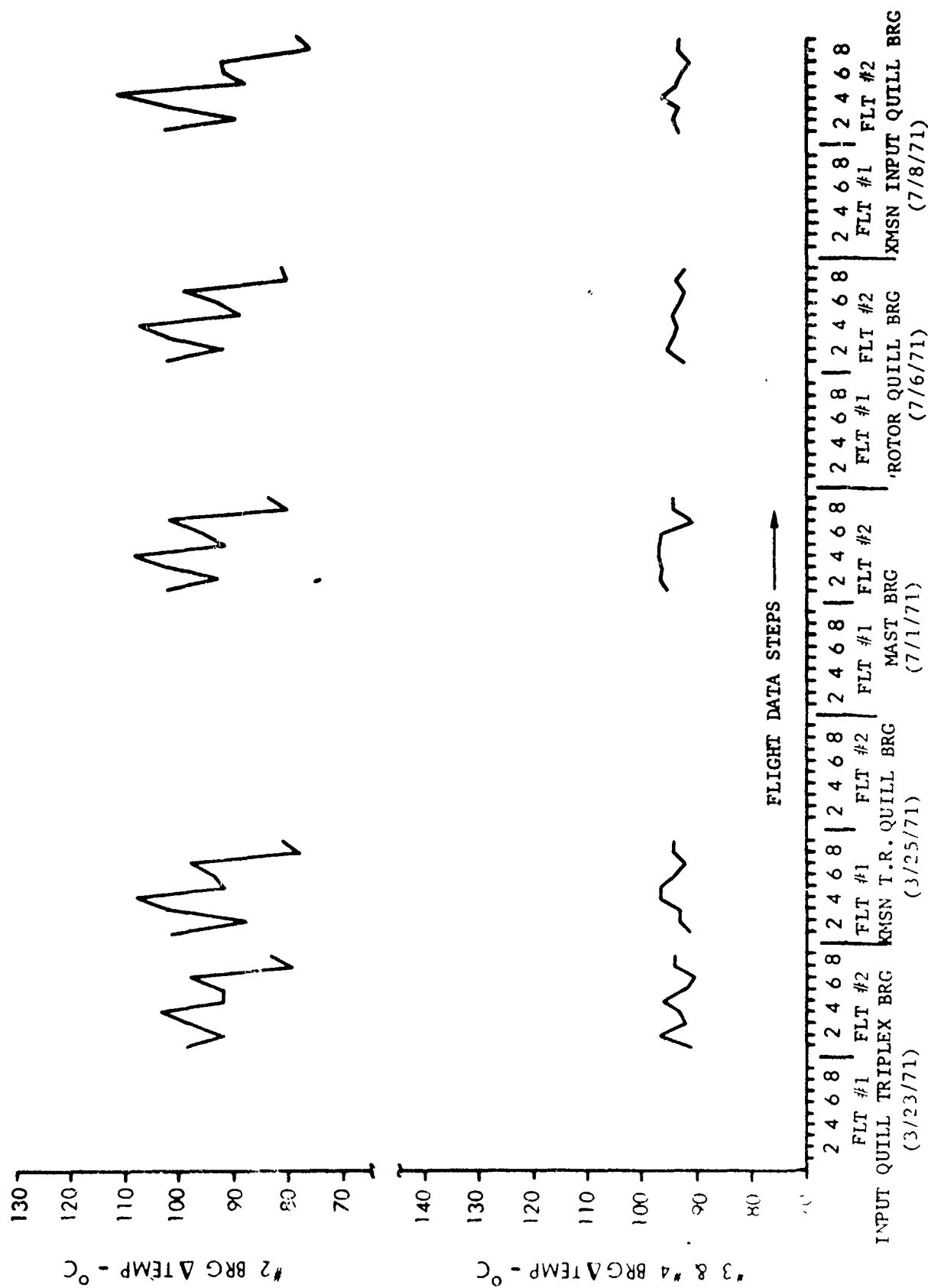
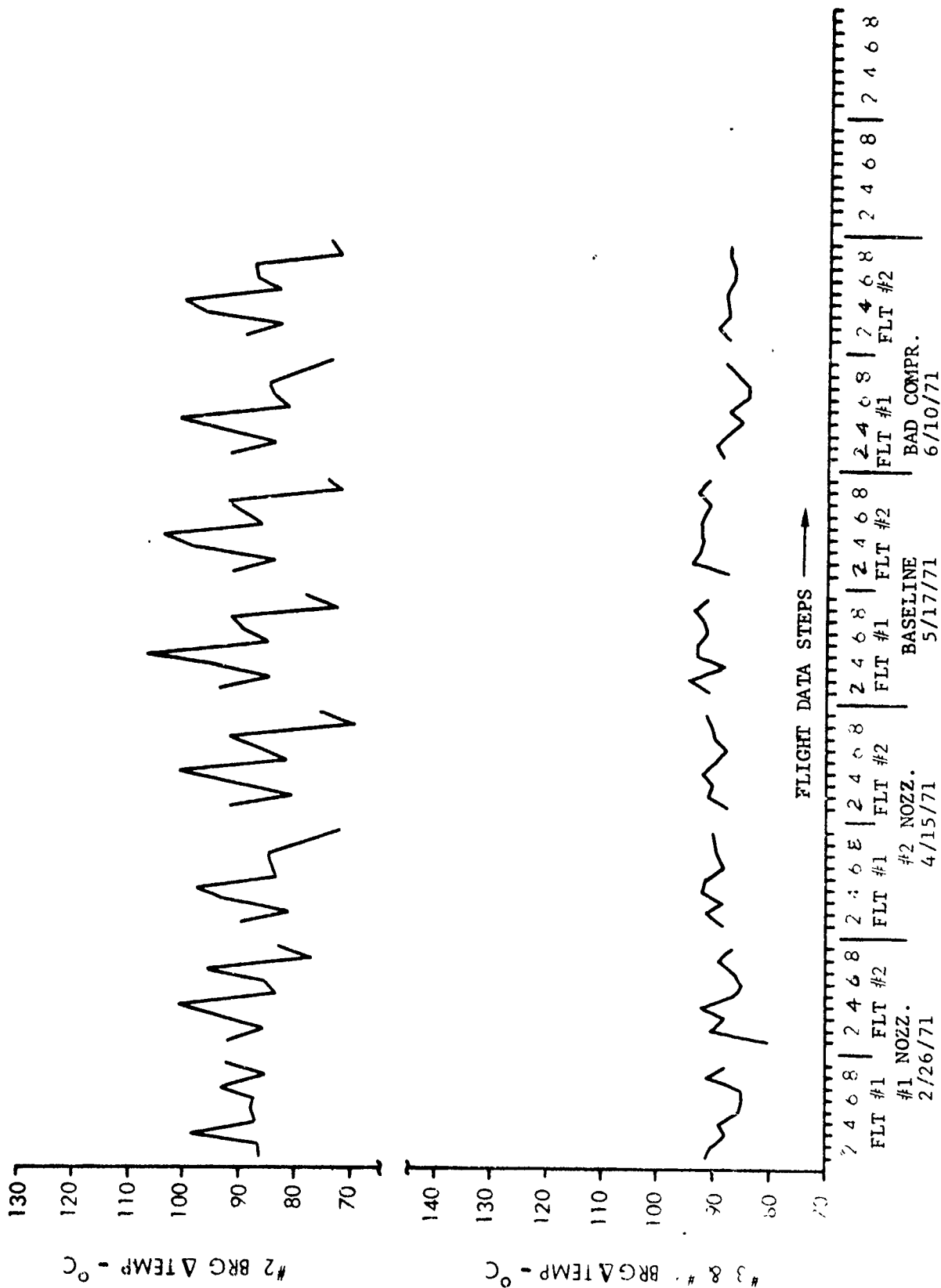


FIGURE 7-97 BEARING DIFFERENTIAL TEMPERATURE FOR ENG 3/N 18518 - A/C 67-17448



FIGURE 7-98 BEARING DIFFERENTIAL TEMPERATURE FOR ENG S/N 20727 - A/C 67-17448





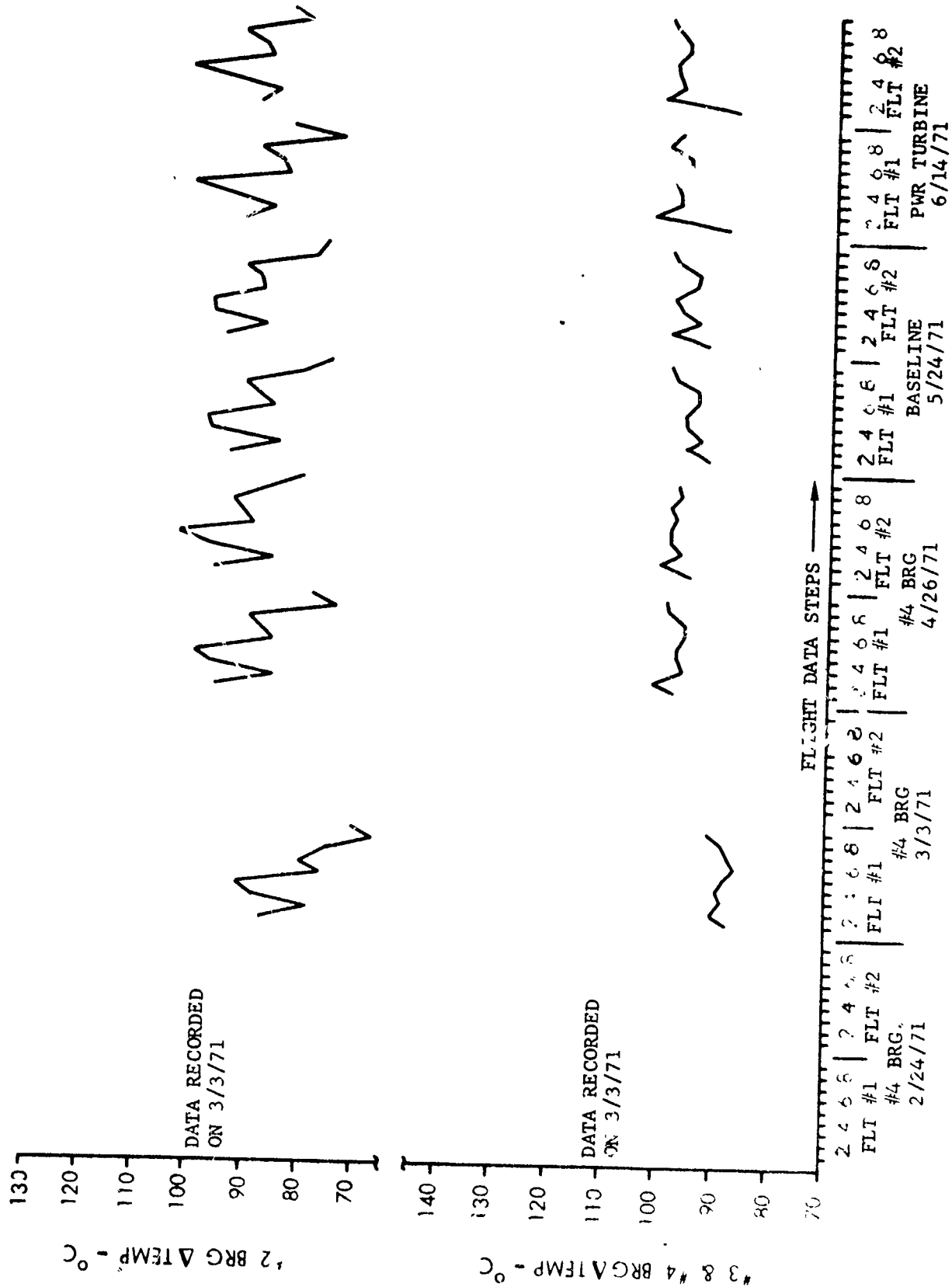


FIGURE 7-101 BEARING DIFFERENTIAL TEMPERATURE FOR ENG S/N 15351 - A/C 67-17448

No. 3 and No. 4 bearing differential temperature, that disturbing the No. 2 bearing assembly during the teardown and build-up cycle of the engine caused shifts in the monitored temperature. A test which accumulated many more hours of operation of a discrepant number 2 bearing would provide a means of evaluating a degrading condition. The test should probably be conducted in a test cell and a discrepant implant (moderate) is suggested to reduce test time.

The sensitivity of this monitoring method, as indicated in figures 7-97 through 7-101, would provide an effective means of detecting a leaky bearing seal. A leaky seal directly affects scavenge oil temperature and would cause temperature changes which could easily be detected.

#### 7.7.3.2 No. 3 and No. 4 Bearing $\Delta T$

Monitoring potential of the No. 3 and No. 4 bearing differential temperature was demonstrated on the flight of 19 February 1971 using engine S/N 20727. A maintenance malfunction occurred on the second flight indicating high No. 3 and No. 4 temperature. An inspection of the bearing assembly was requested in order to verify the condition of the implanted bearing. The investigation after teardown indicated that the No. 3 bearing discrepant implant had not worsened in condition but a slight leak at the scavenge port on the bearing housing had caused the temperature to rise to an abnormal value (see figure 7-102). This is the same type of temperature situation that would occur with a leaking bearing seal.

As in the case of the No. 2 bearing, it is very difficult to see any correlation of differential temperature to the presence of a discrepant implant (see figures 7-97 through 7-101). This parameter exhibited a sensitivity to the teardown/build-up cycle of implanting discrepant parts by shifting temperature level nearly every time. Some engines, as in the case of 20727, were more sensitive than others.

Fortunately, the many data points acquired from the normal service engine (S/N 18918), which was not torn down, established a constancy of temperature level when flown using the same discrepant profile for transmission tests (a variation of no more than 5°C was observed for a given step of the profile). This consistency and the demonstrated sensitivity to engine power conditions

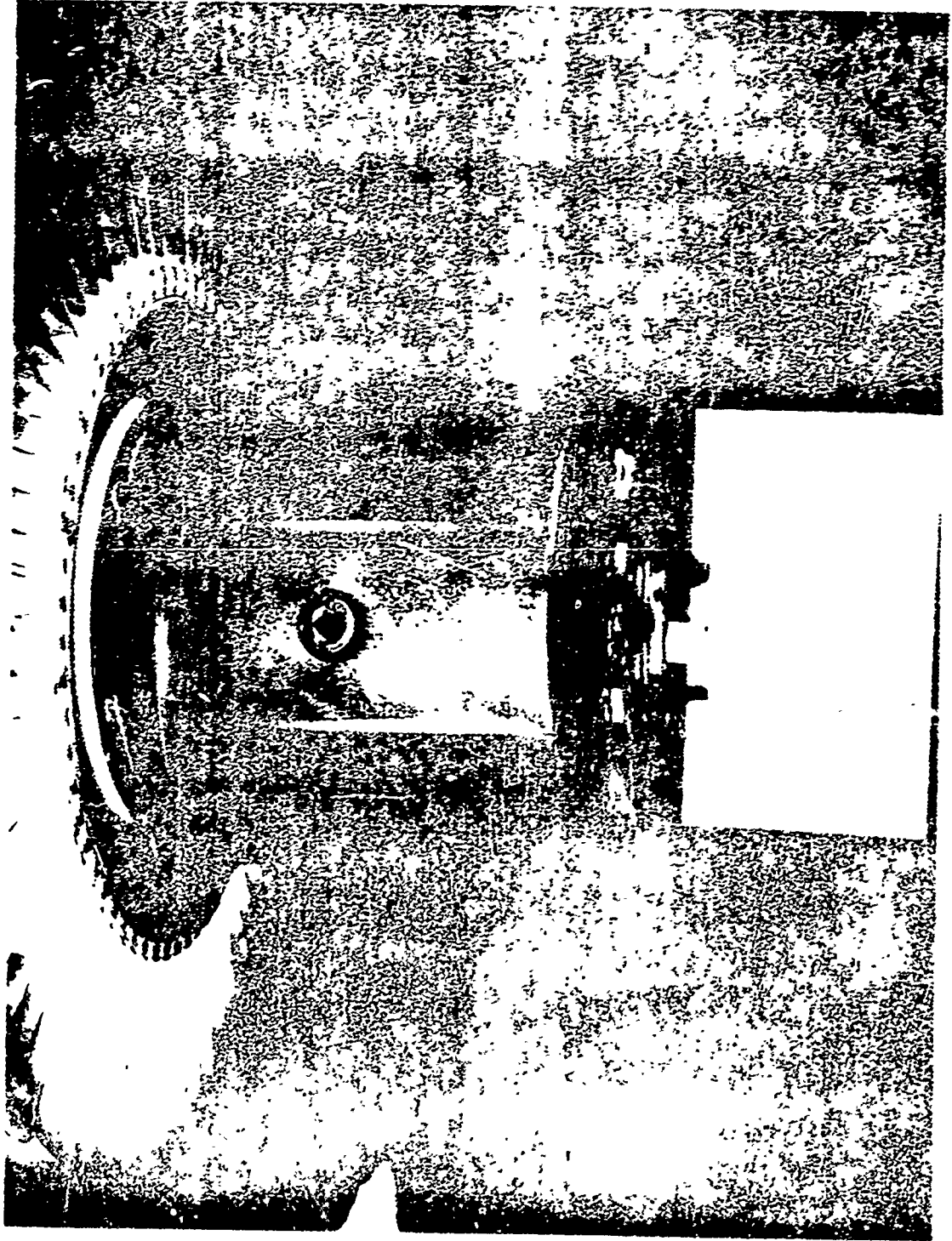


FIGURE 7-102 LEAKY NO. 3 & NO. 4 BEARING HOUSINGS

(EGT) could be used as a prognostic indicator. By limiting a data sample of the differential temperature to a given value of  $N_1$  or torque, small changes in excess of "health" limit could be detected. The detected change would indicate a hot section problem rather than a definite bearing problem.

#### 7.7.3.3 90° $\Delta T$ and 42° $\Delta T$ (See Figures 7-103, 7-104, and 7-105)

Evaluation of the gearbox differential temperatures indicated that there was no definite correlation of temperature to discrepant implants. At some power levels, slight increases in temperature were observed for some of the discrepant parts. Correlation to discrepant implants may have been as successful in flight test as it was in the test cell if higher gearbox input power could have been used. The higher levels, however, could not be realized in flight.

Only input and output bearings were used for discrepant implants; gears were not used in flight as they were in the cell.

### 7.8 TREND AIRCRAFT

Using a normal MRS installation, aircraft 67-17138 was flown to accumulate as many flight hours as possible so that normal wear and deterioration of components could be evaluated. The objective was to actually detect changes (trends) as they occur, thus enabling prognosis of incipient failures to be made. The ability to accomplish this objective was made more difficult by the fact that aircraft 67-17138 was a newly overhauled helicopter, and any flight hours accumulated would be the first flown.

Except for a few special flights, no special constraints were placed on aircraft 67-17138 flights. The aircraft was flown on normal missions at Corpus Christi. This approach was compatible with the operations at Corpus Christi because the prevailing weather conditions did not excessively limit flying and any of the available UH-1 pilots could be used for flights.

Since a Leach instrumentation recorder was not used on aircraft 67-17138 and because the MRS mechanization could not store broadband vibration data, no vibration trends could be established.

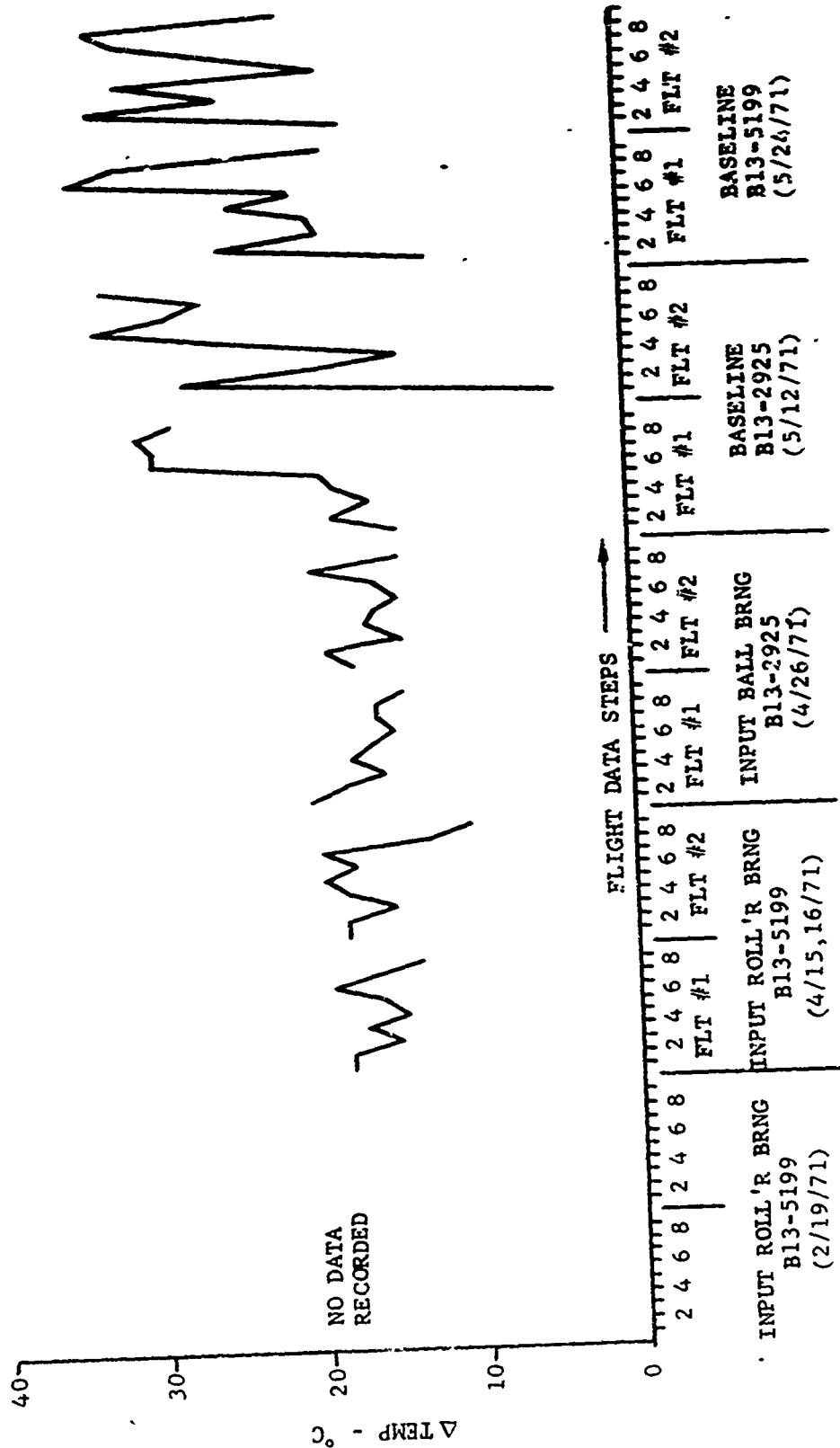


FIGURE 7-103 42° GEARBOX DIFFERENTIAL TEMPERATURE - A/C 67-17448

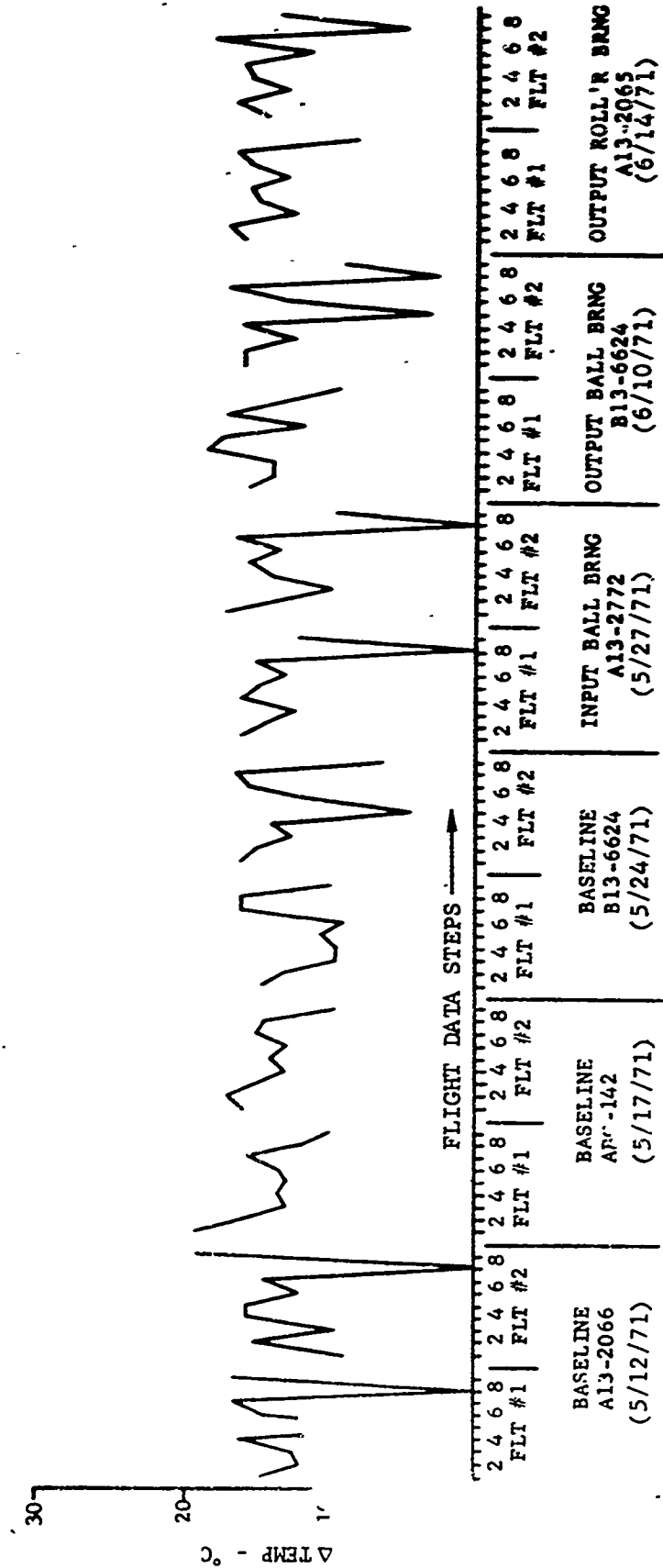


FIGURE 7-104 90° GEARBOX DIFFERENTIAL TEMPERATURE - A/C 67-17448



**- A/C 67-17448**

### 7.8.1 TREND ANALYSIS

The UH-1H trend helicopter powered by engine S/N 16382 was employed to obtain engine performance degradation characteristics. Total engine running time of approximately 236 hours (T53-13A engine, TBO - 1,200 hours) was logged on this engine during the period of 20 January 1971 to 8 July 1971. Figures 7-106 through 7-125 present the plot of engine compressor pressure ratio, corrected exhaust gas temperature, corrected shaft horsepower, and engine fuel flow as a function of corrected engine speed. Each figure presents the engine performance data for all flights conducted during each month. Useful engine data was not recorded on the MRS unit until the month of March, since during the initial phase (January and February) the trend aircraft was used to check out various aircraft system operations, flight profiles, and the data acquisition system. Direct comparisons of the engine performance data for the March and July flight tests presented in figures 7-123 through 7-125 show slightly higher engine performance values are indicated during the later flights. This is because the fuel control was changed in March due to a droop problem. The engine fuel flow cannot be compared because it was recorded only on the last few flights (verification check flights on 2 July 1971 and 7 July 1971). The results of A/C 67-17448 flight test data from the service engine showed no significant change in engine performance (see figures 7-126 through 7-130). The accumulated engine running time was apparently not sufficient to degrade the engine S/N 16382 performance characteristics. Additional engine running time is recommended to obtain more meaningful engine performance trending data.

During the more than 90 flights on aircraft 67-17132, several types of maintenance codes were output by the MRS. Each output which occurred was evaluated and verified at Corpus Christi as soon after occurrence as possible. The types of codes and the significance of the occurrence are detailed below.

- a) Lower limit overtorques (greater than 50 psi) occurred many times during the program. Investigation of occurrences revealed that the basic problem was that the MRS, which was accurately calibrated to a known standard, was outputting accurately and the pilots cockpit indicator was reading 2 to 2.5 psi lower when checked at the same time (a similar situation was evident on aircraft 67-17448). The indicating error was within the

ENG S/N 16382 FLIGHTS - MONTH OF MARCH, 1971

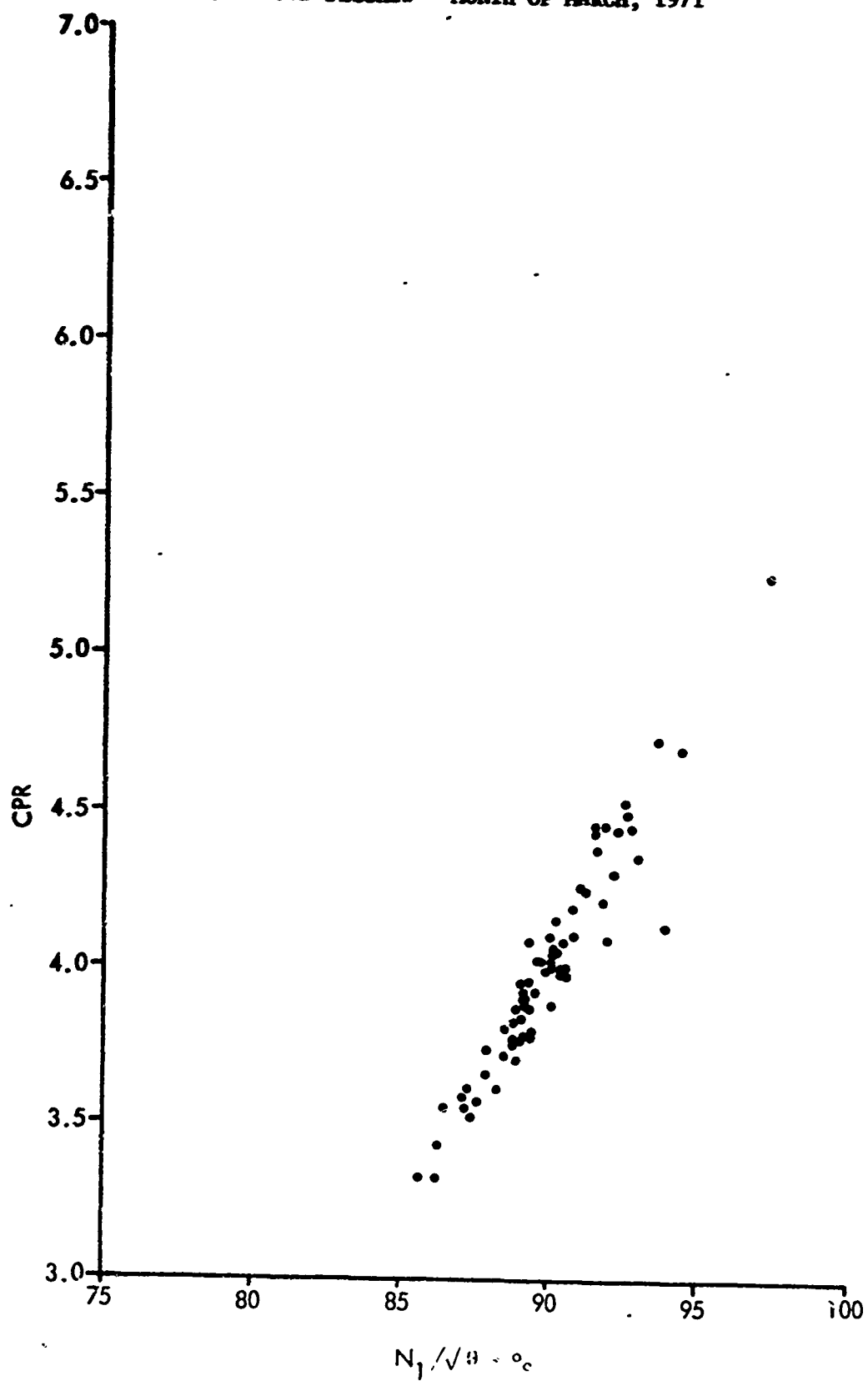


FIGURE 7-106 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

S/N 16382 FLIGHTS - MONTH OF MARCH, 1971

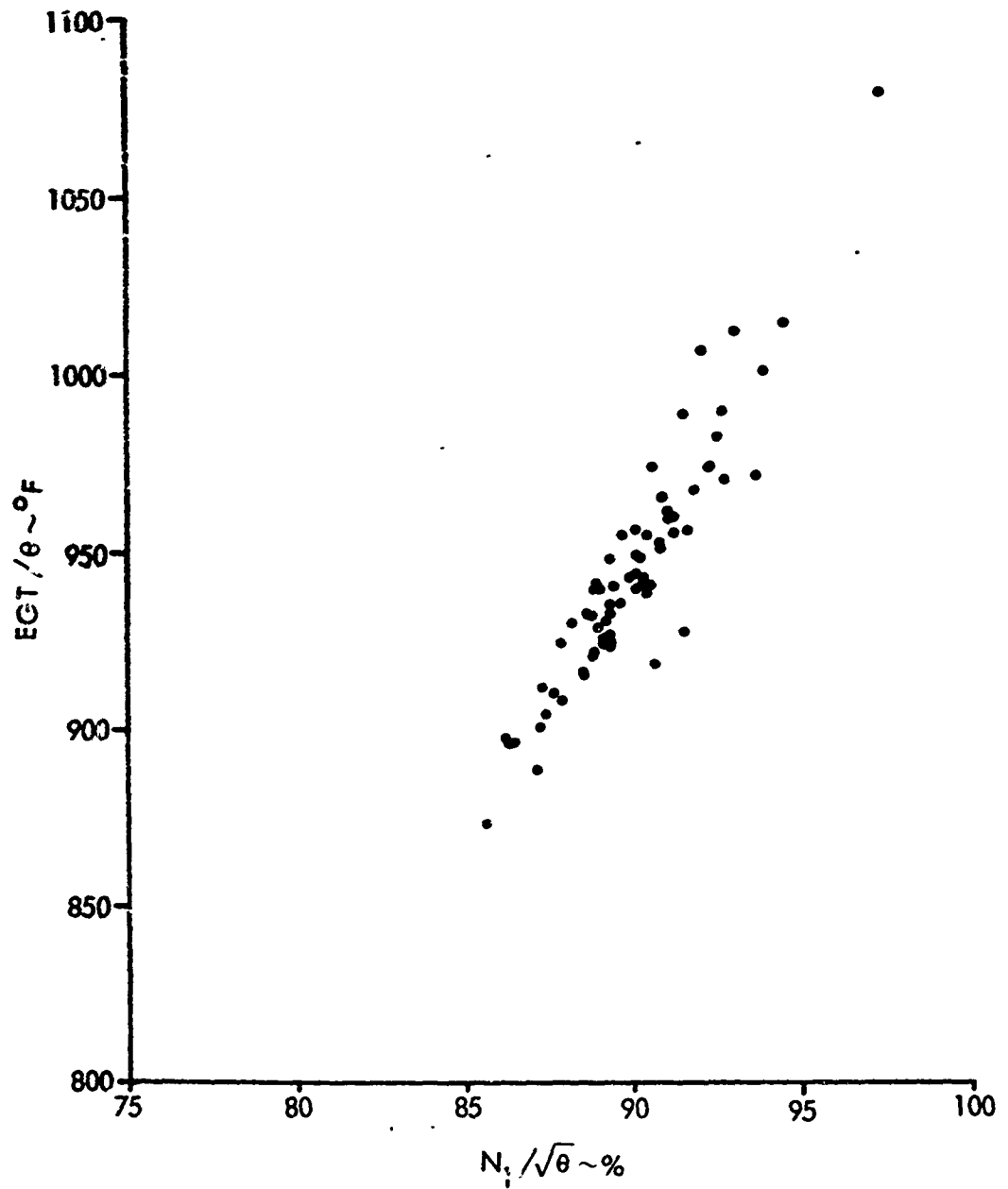


FIGURE 7-107 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

S/N 16382 FLIGHTS - MONTH OF MARCH, 1971

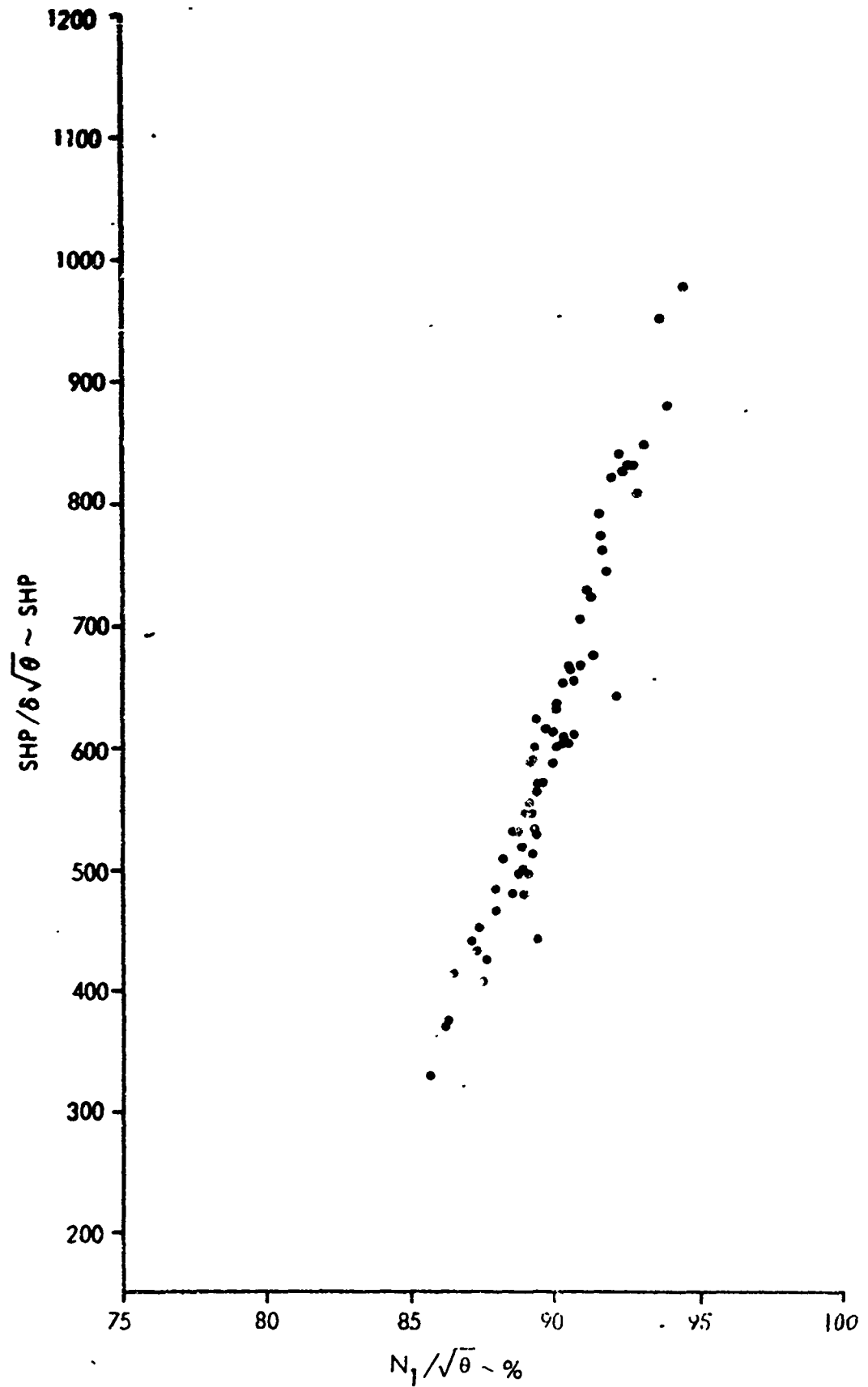


FIGURE 7-108 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

ENG S/N 16382 FLIGHTS - MONTH OF APRIL, 1971

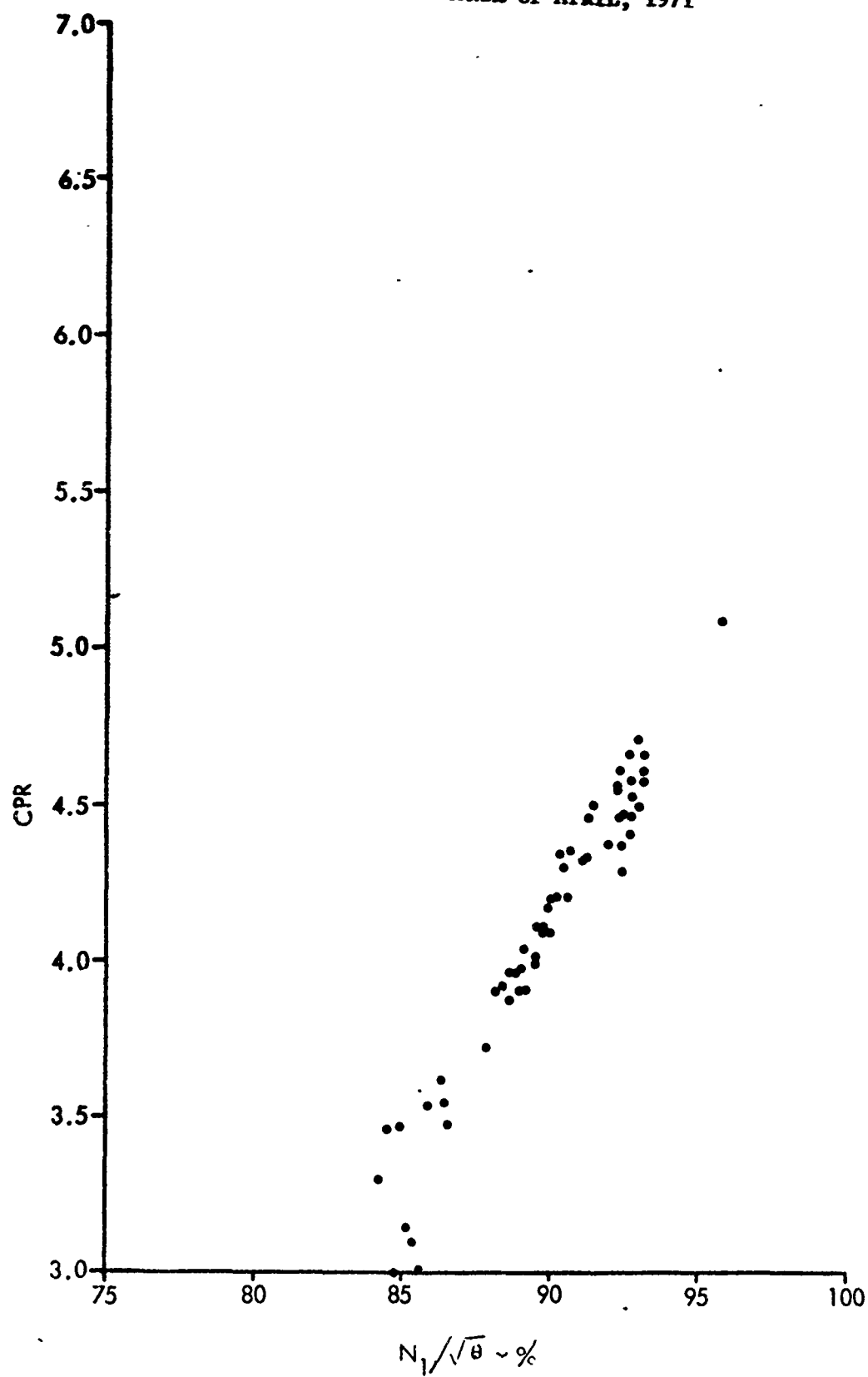


FIGURE 7-109 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

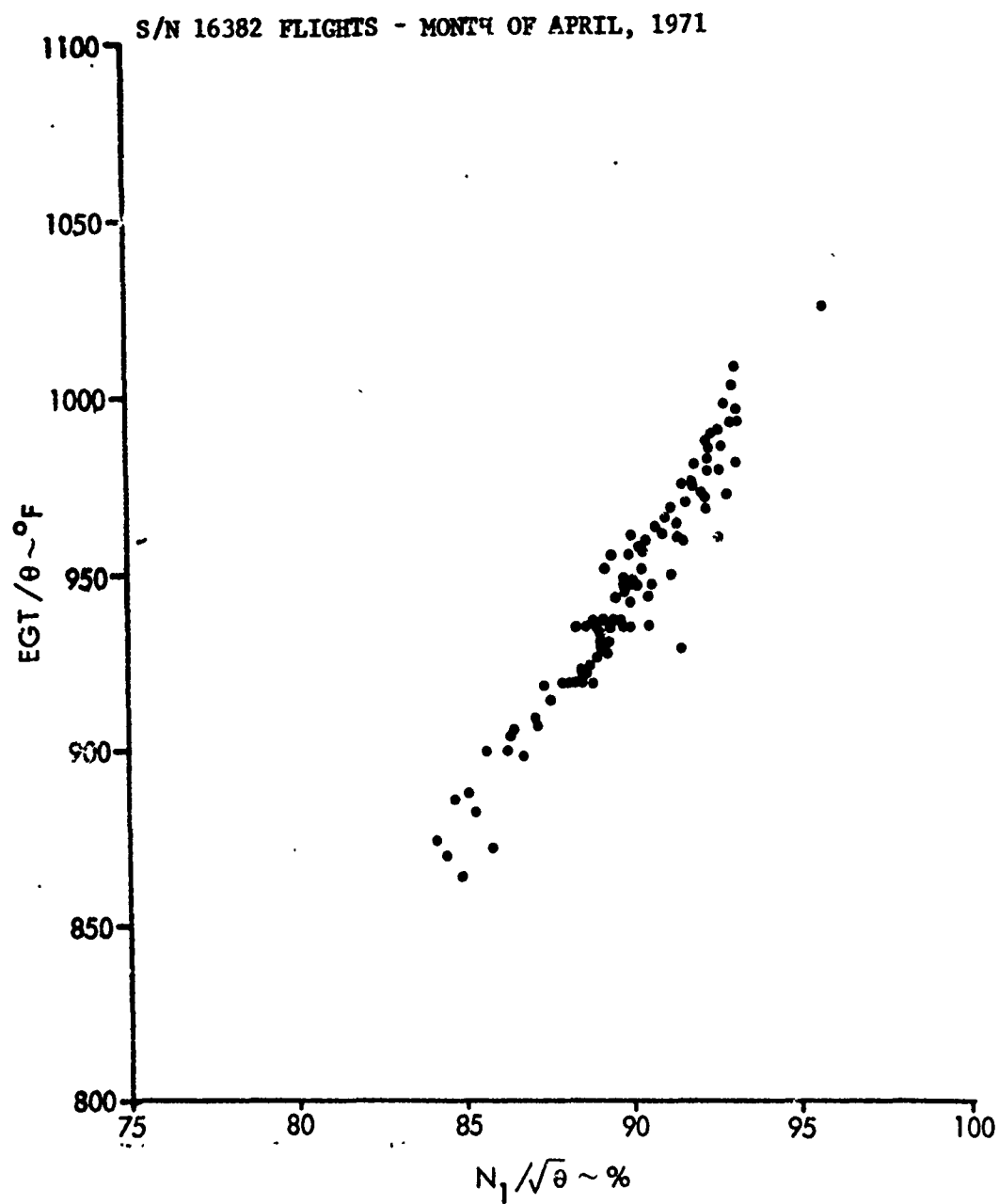


FIGURE 7-110 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

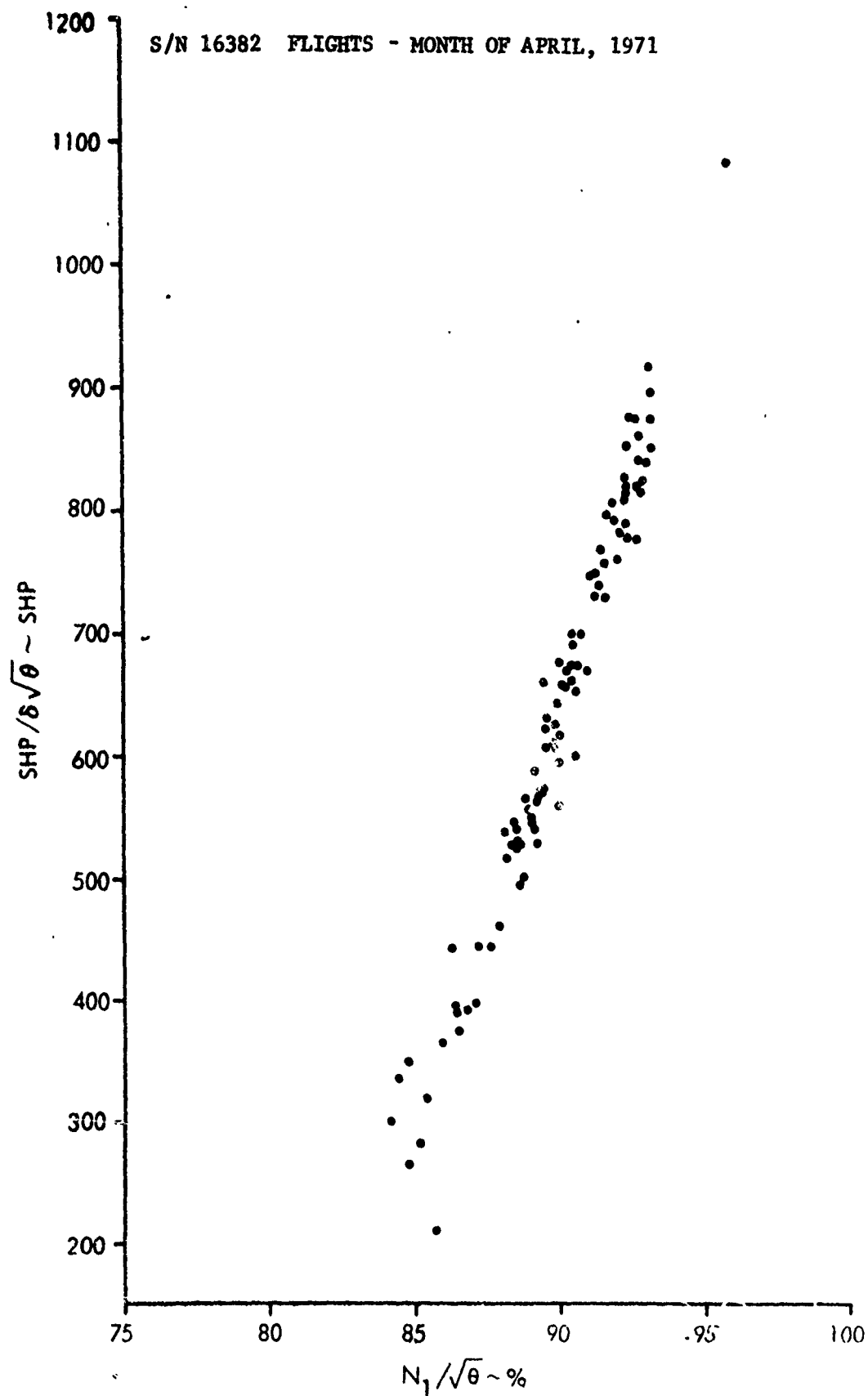


FIGURE 7-111 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

ENG S/N 16382 FLIGHTS - MONTH OF MAY, 1971

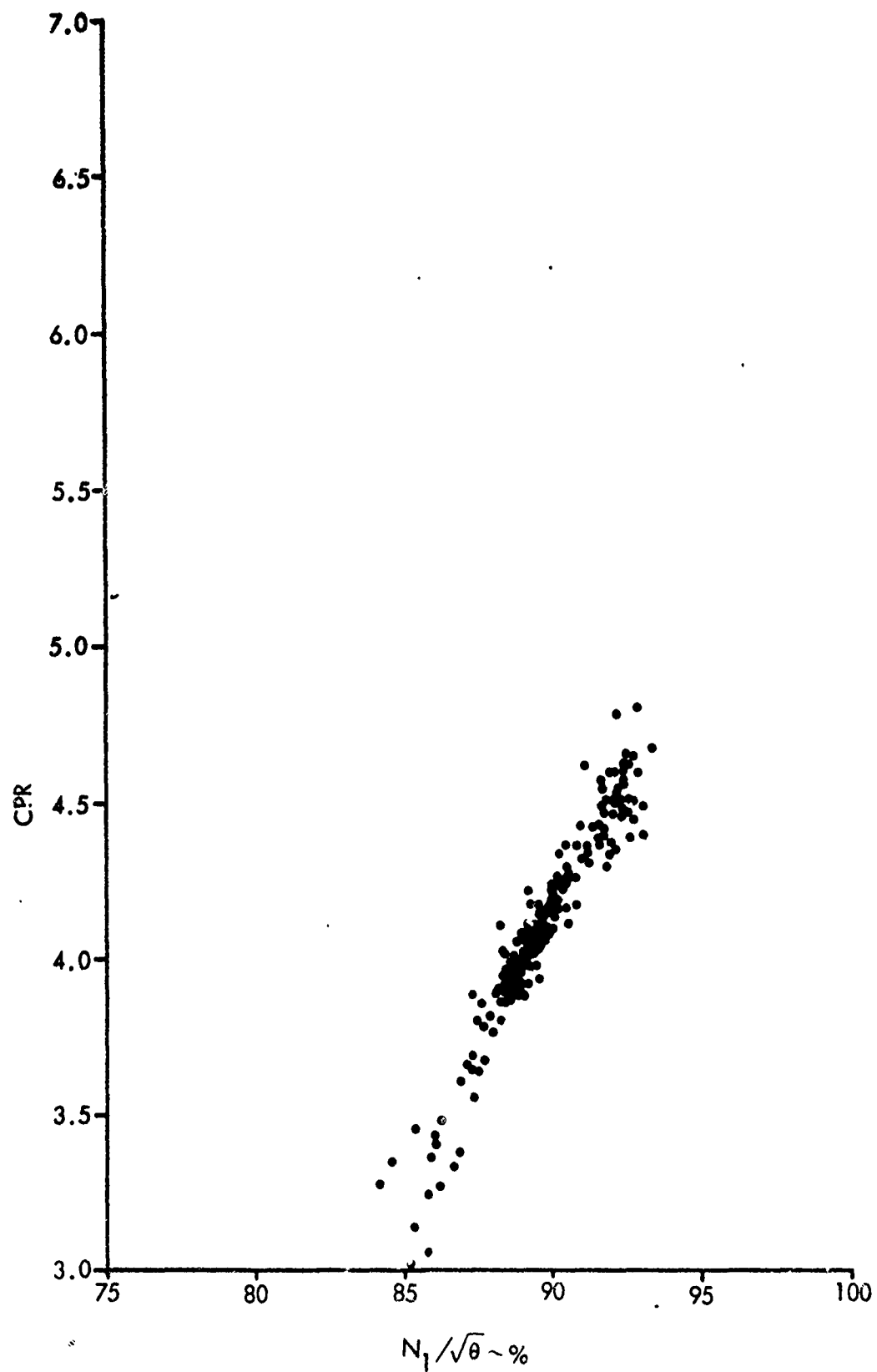


FIGURE 7-112 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

ENG S/N 16382 FLIGHTS - MONTH OF MAY, 1971

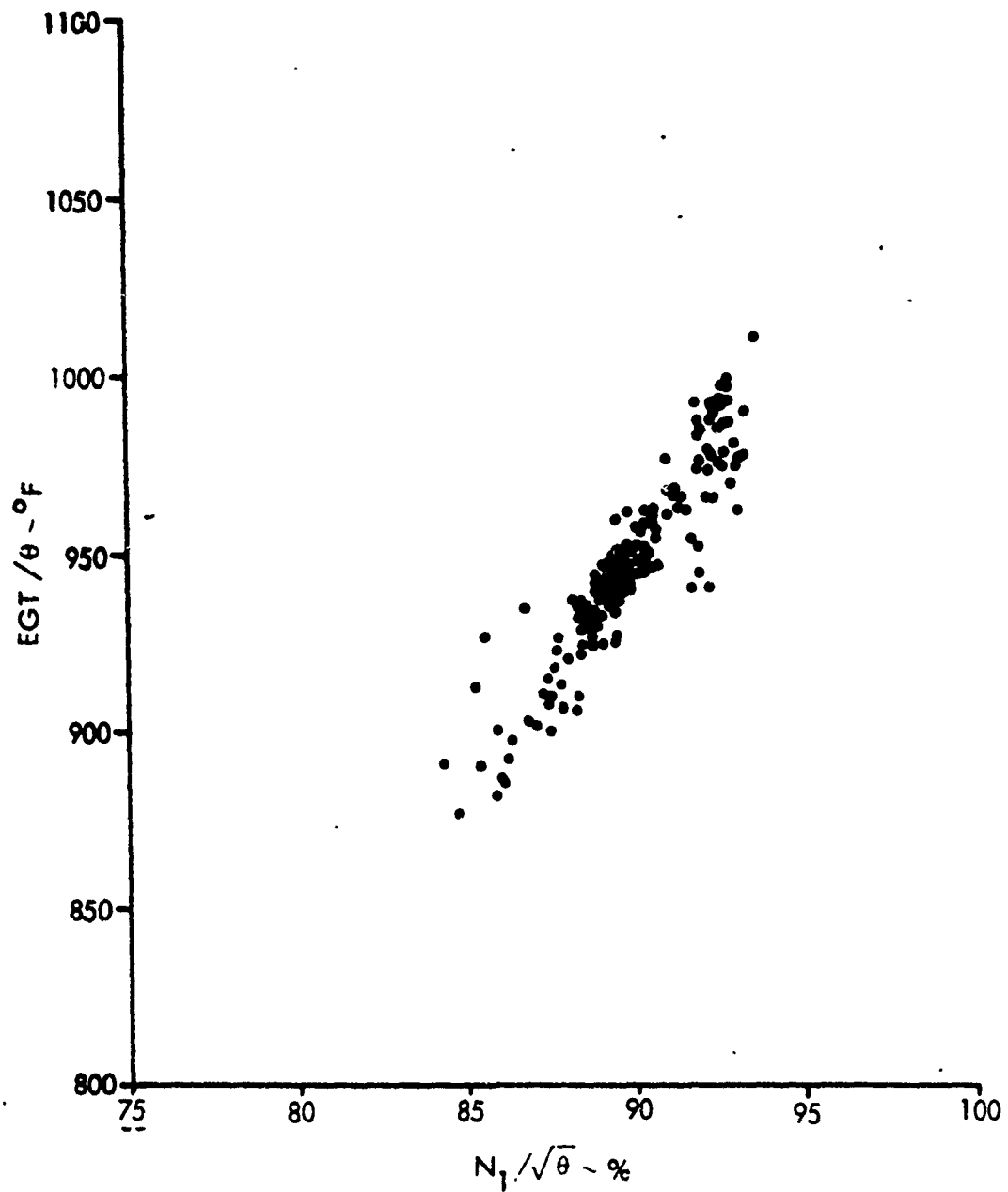


FIGURE 7-113 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

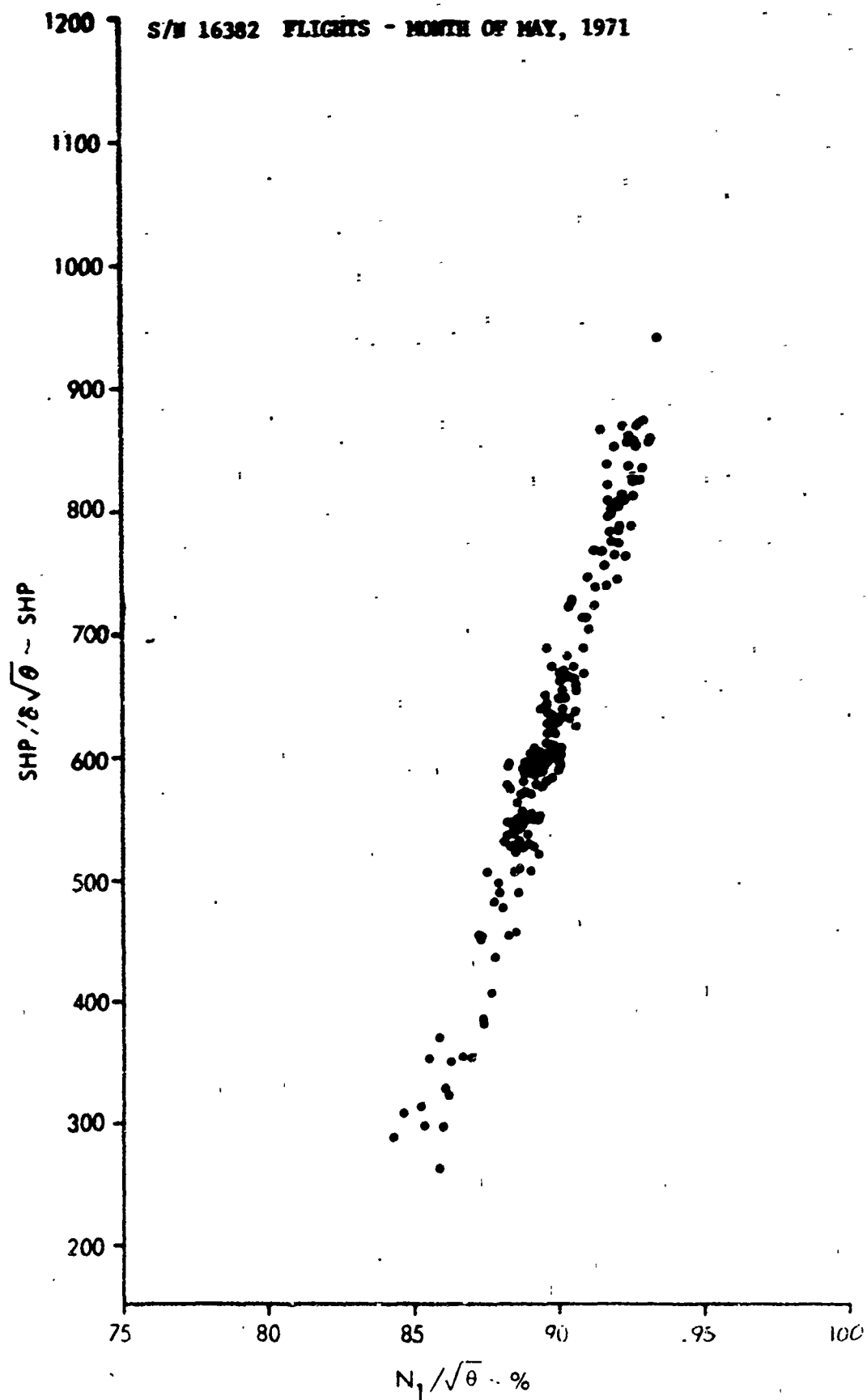


FIGURE 7-114 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

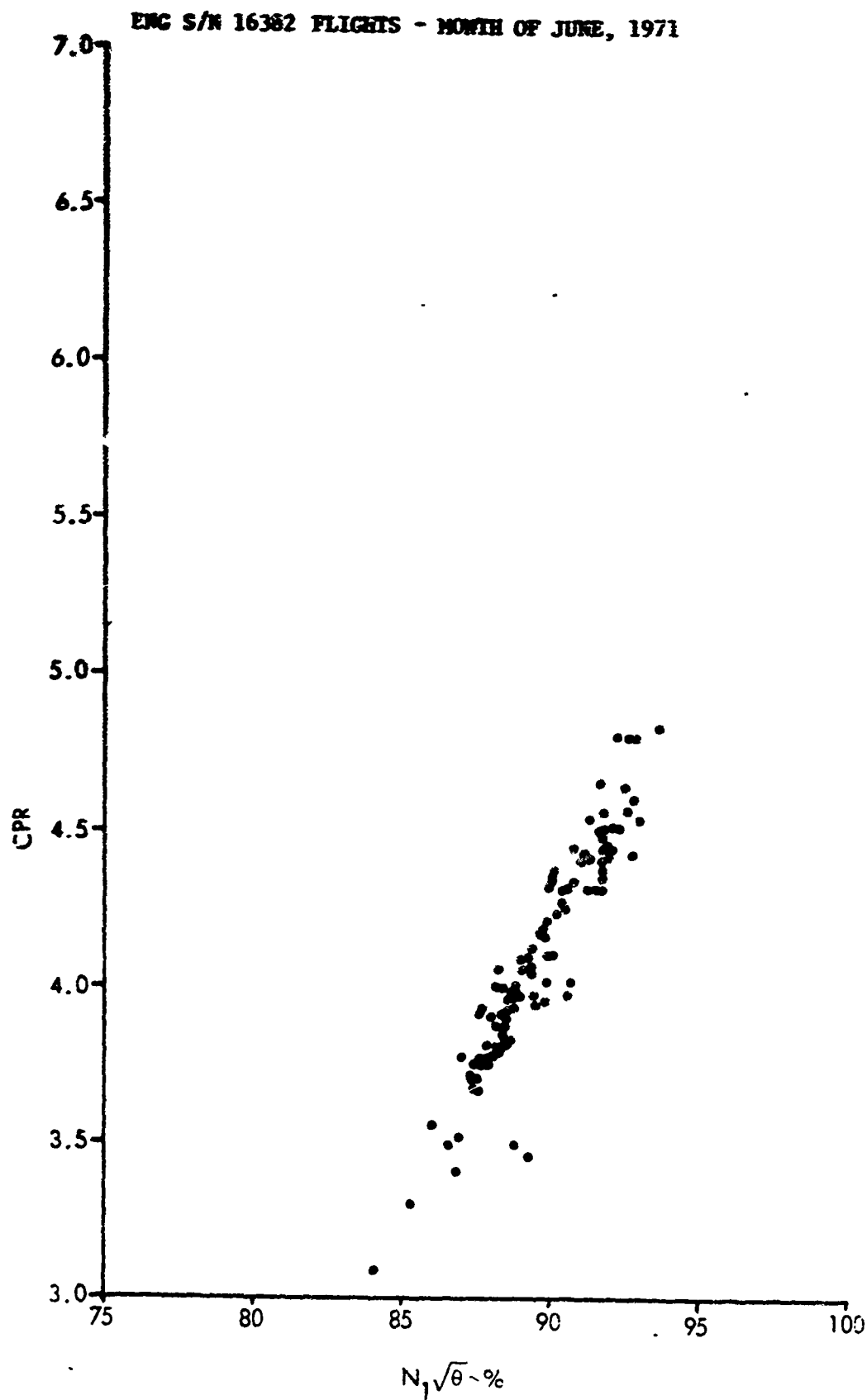
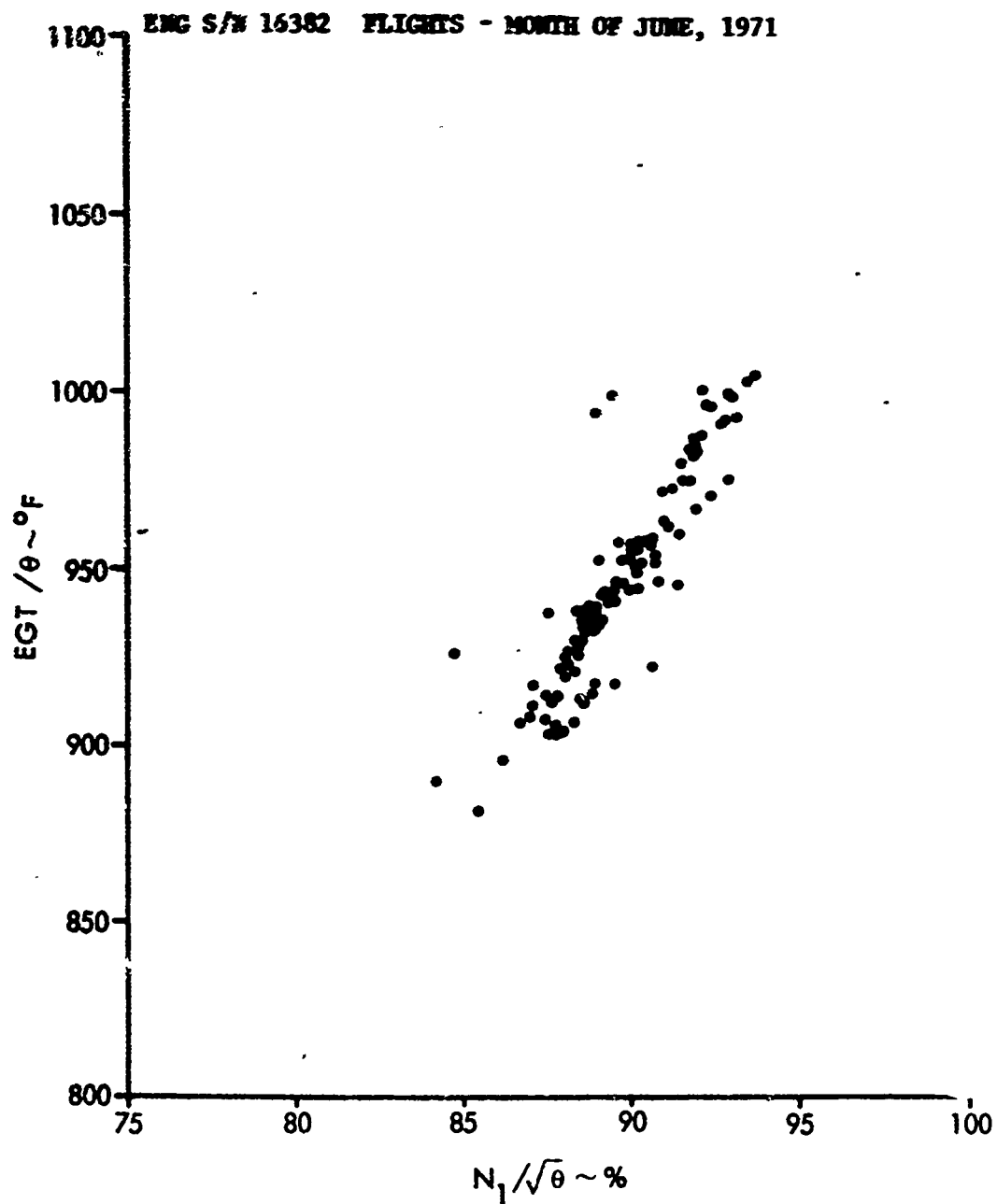


FIGURE 7-115 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED



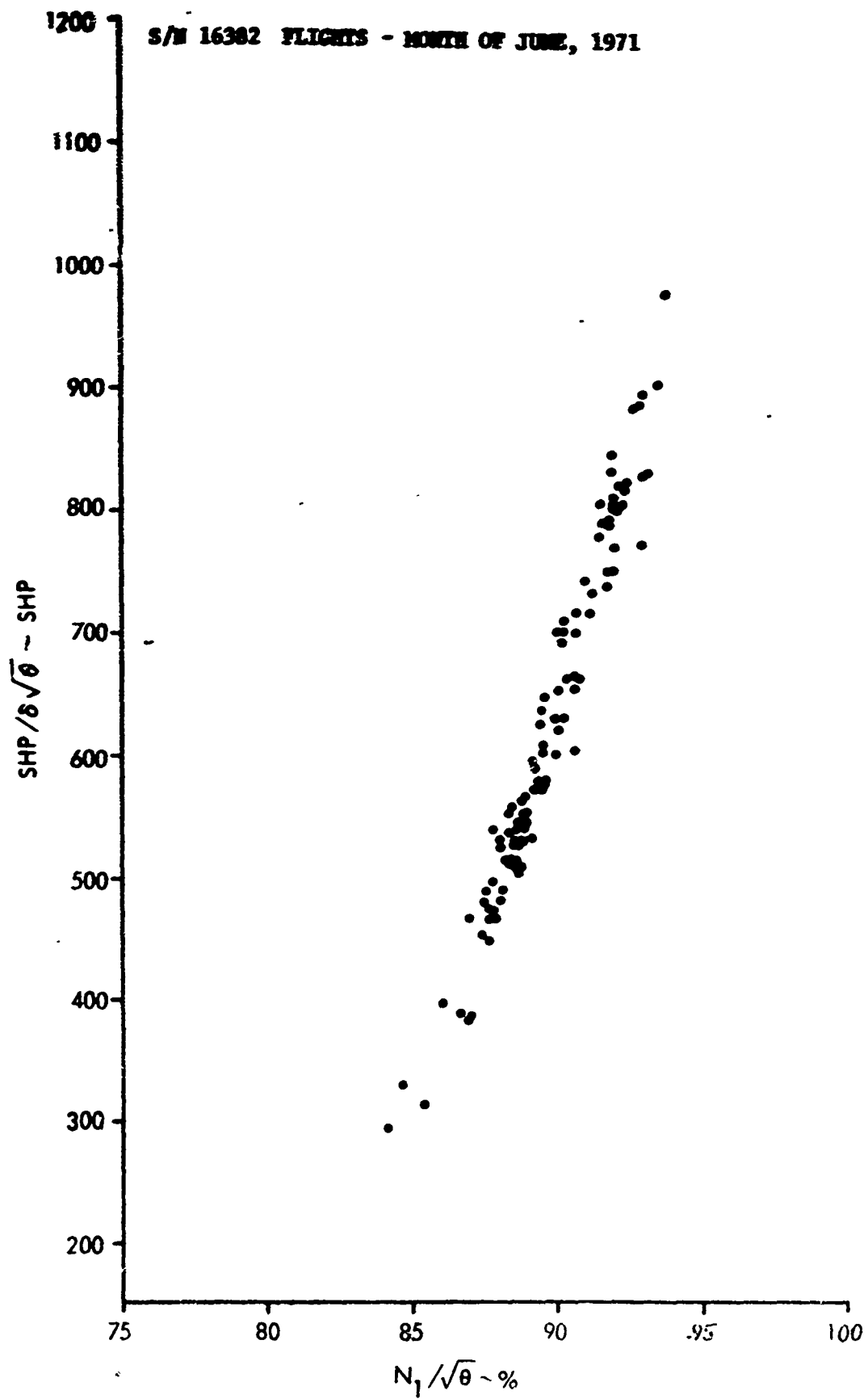


FIGURE 7-117 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

ENG S/N 16382 FLIGHTS - MONTH OF JULY, 1971

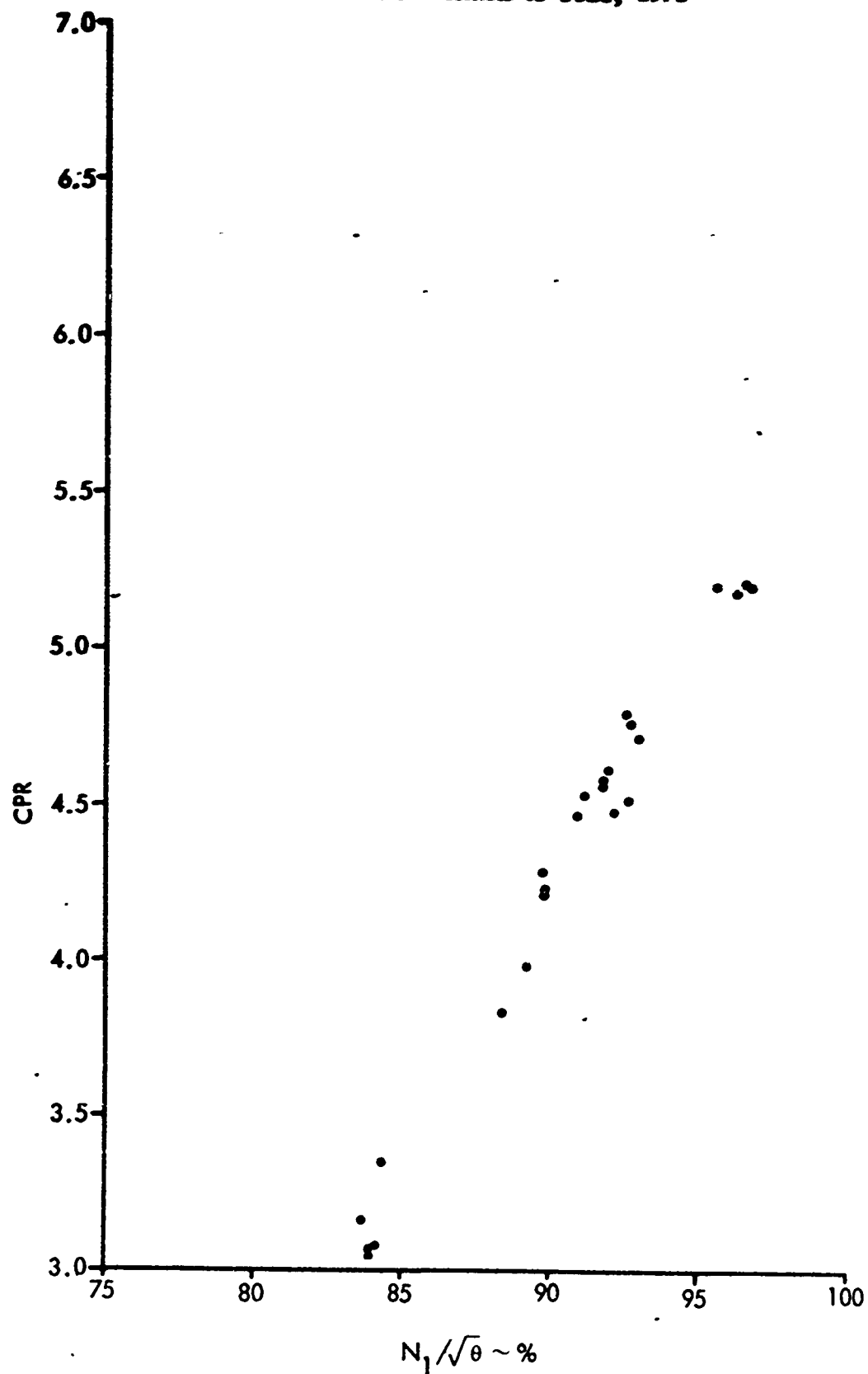


FIGURE 7-118 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

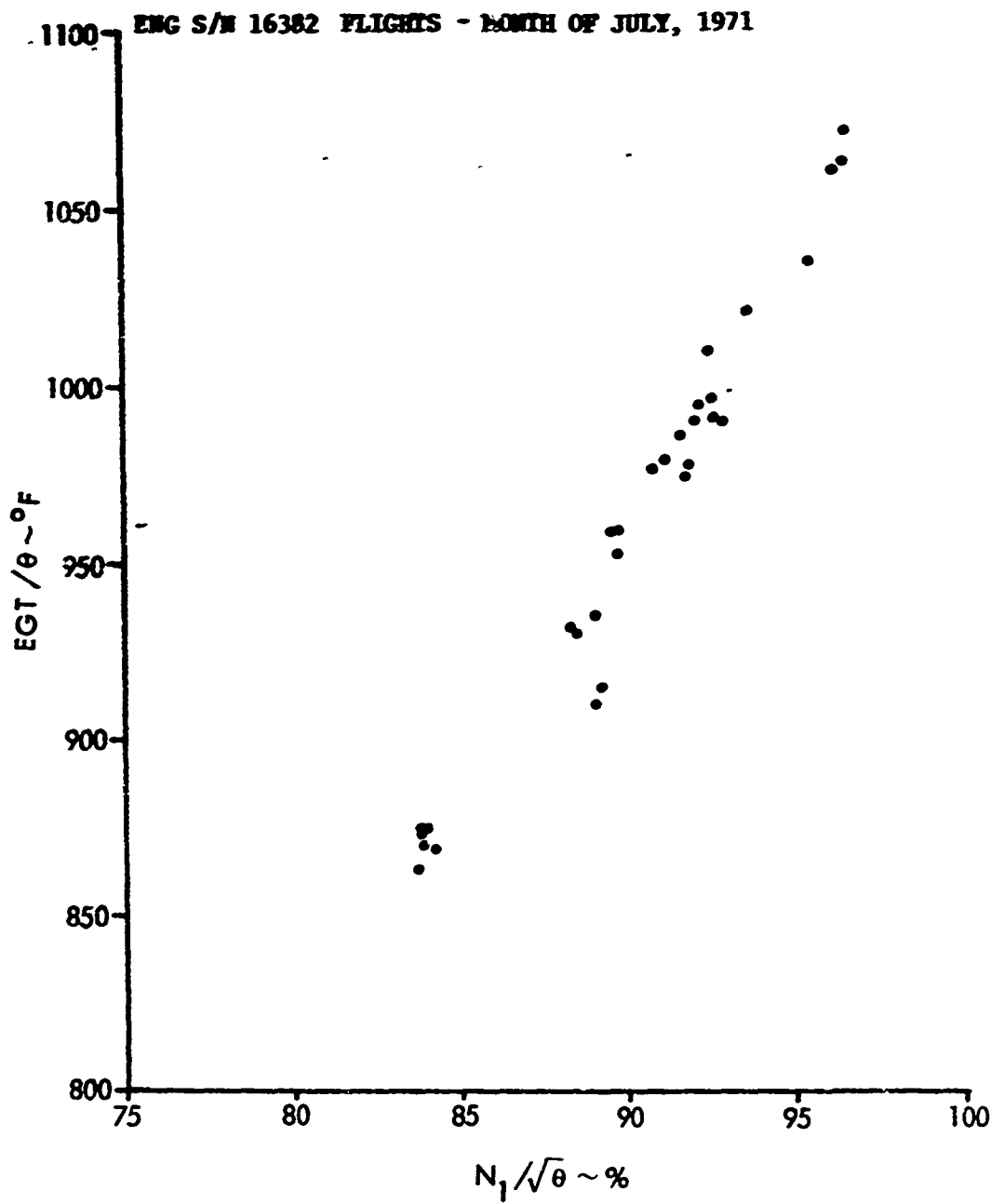


FIGURE 7-119 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

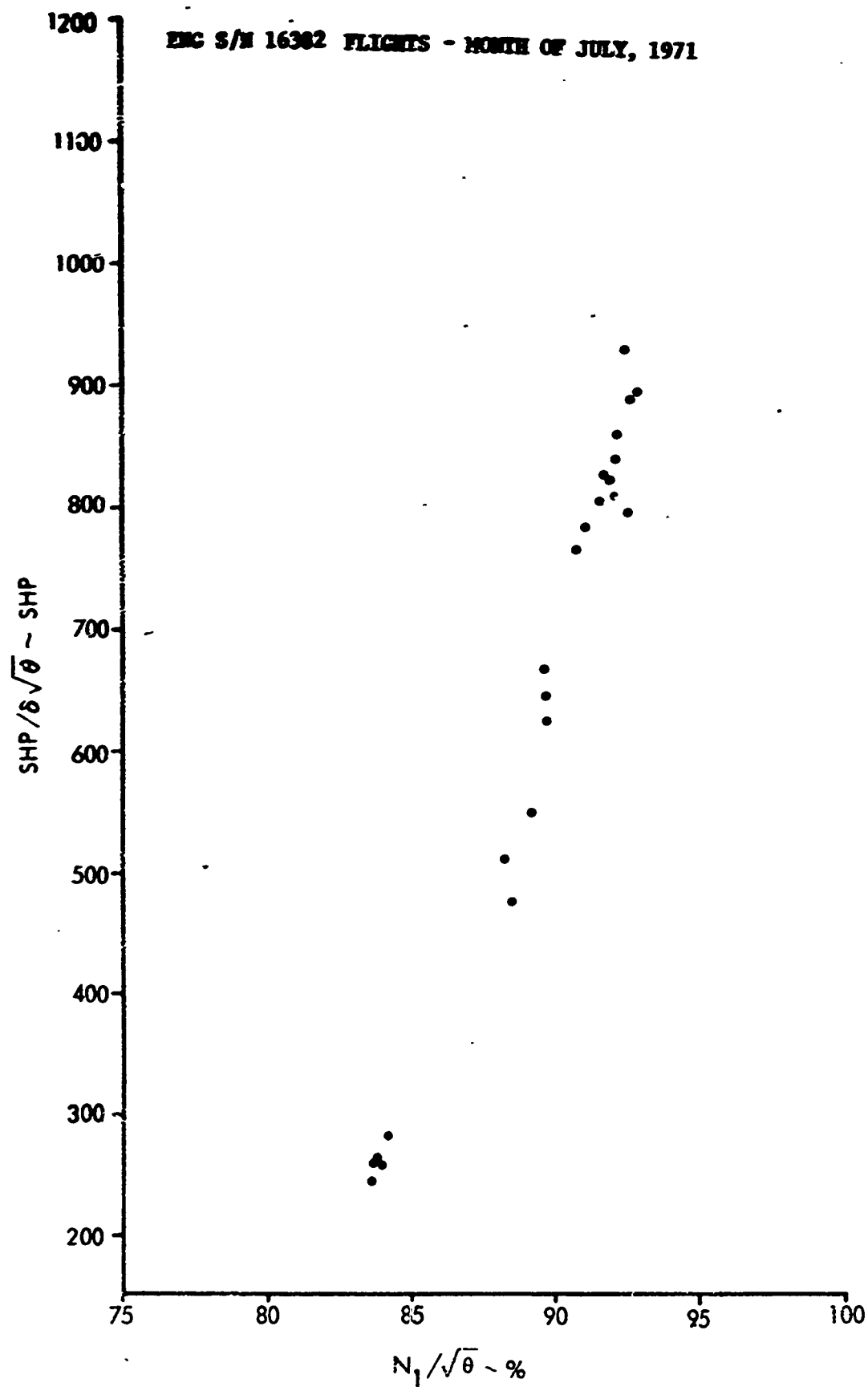


FIGURE 7-120 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

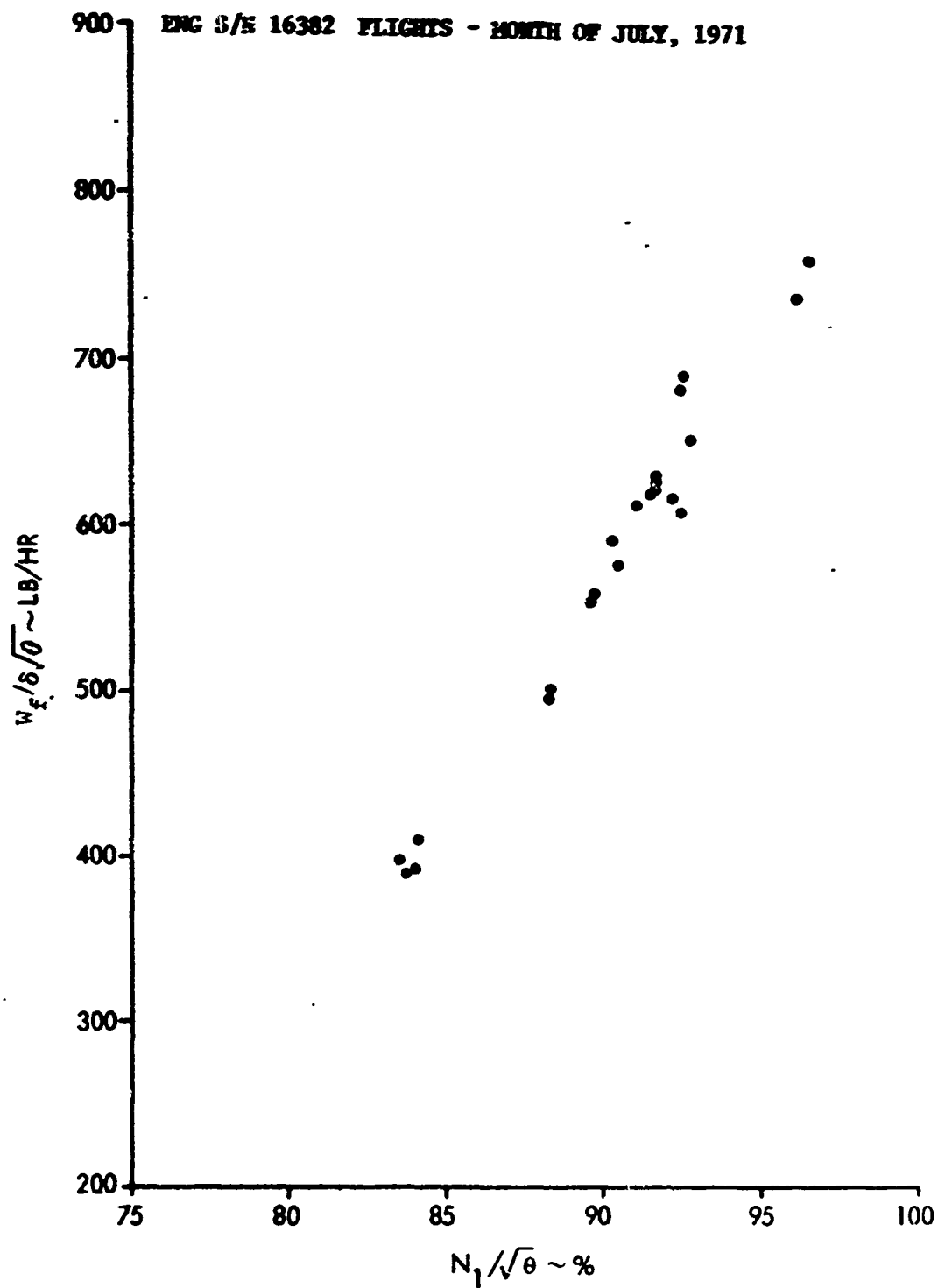


FIGURE 7-121 CORRECTED FUEL FLOW VS CORRECTED  $N_1$  SPEED

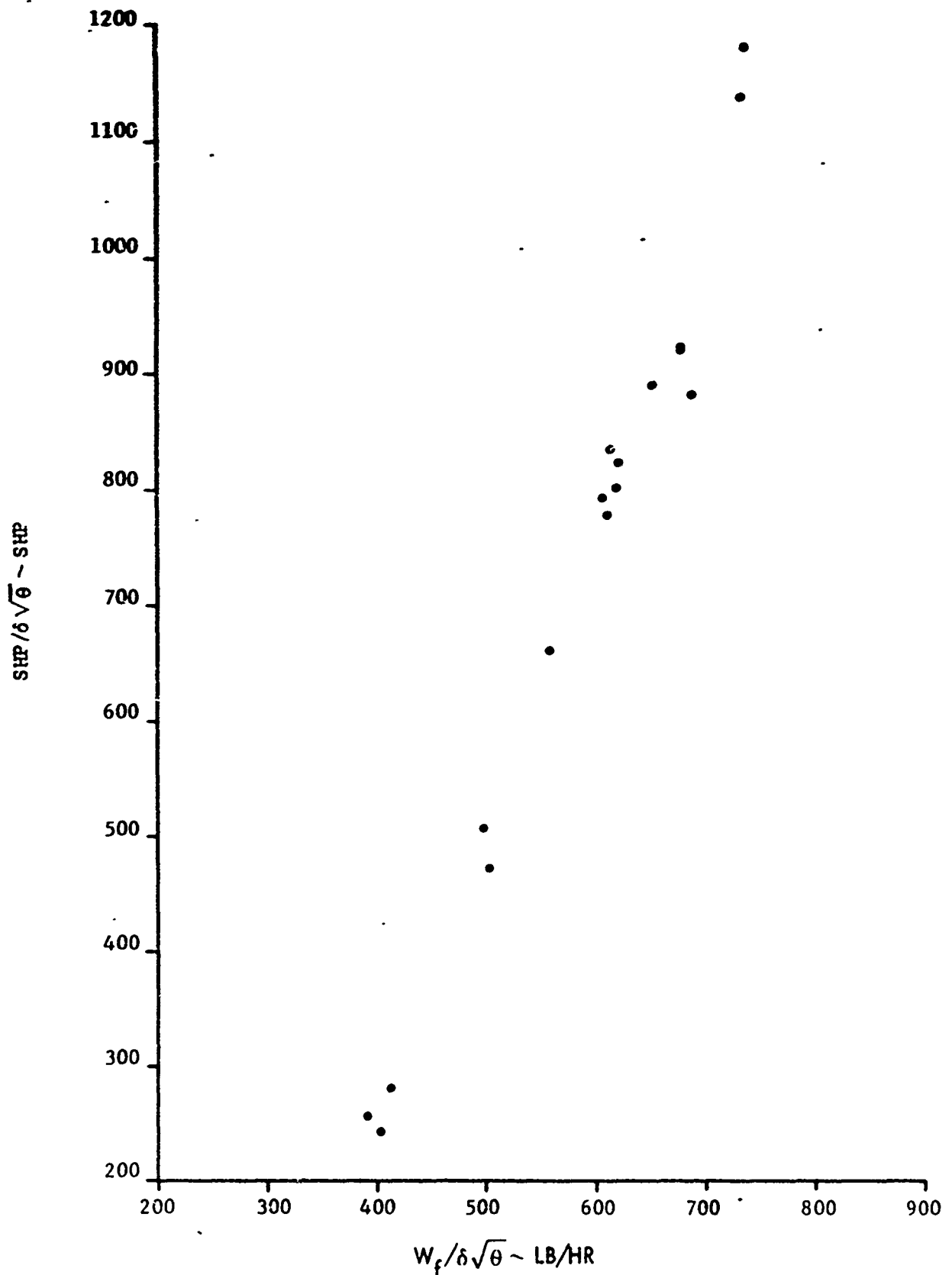


FIGURE 7-122 CORRECTED SHAFT HORSEPOWER VS CORRECTED FUEL FLOW

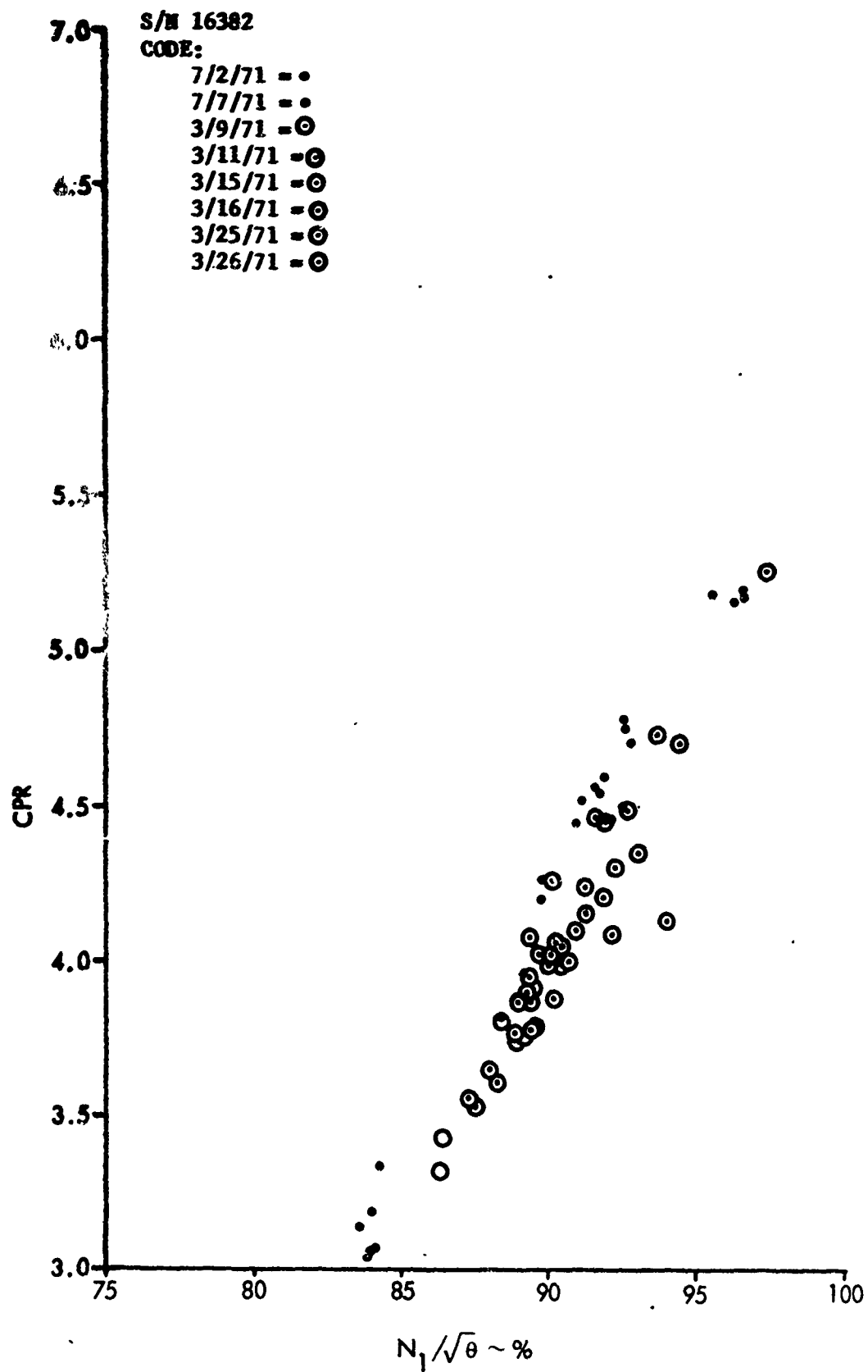


FIGURE 7-123 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

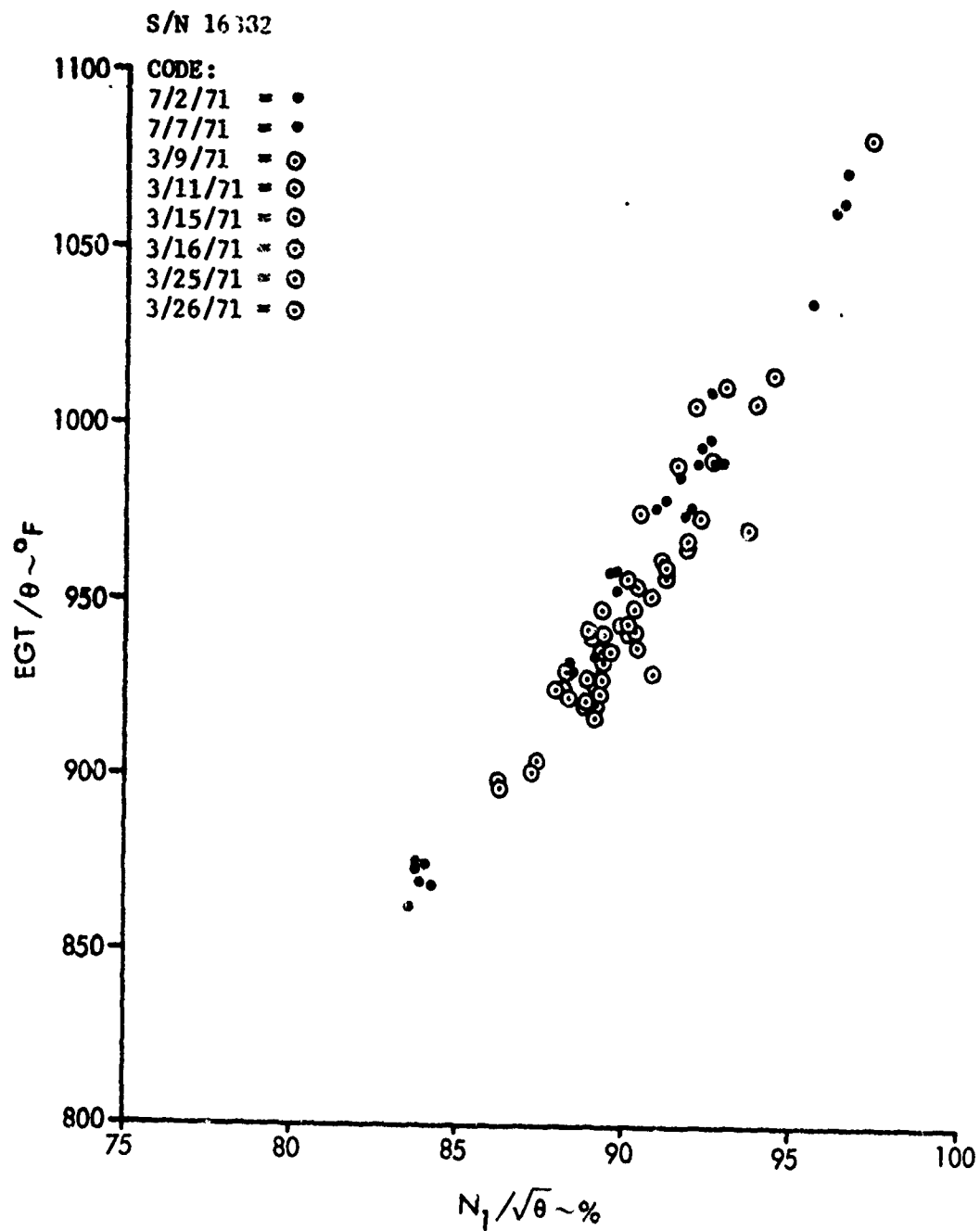


FIGURE 7-124 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

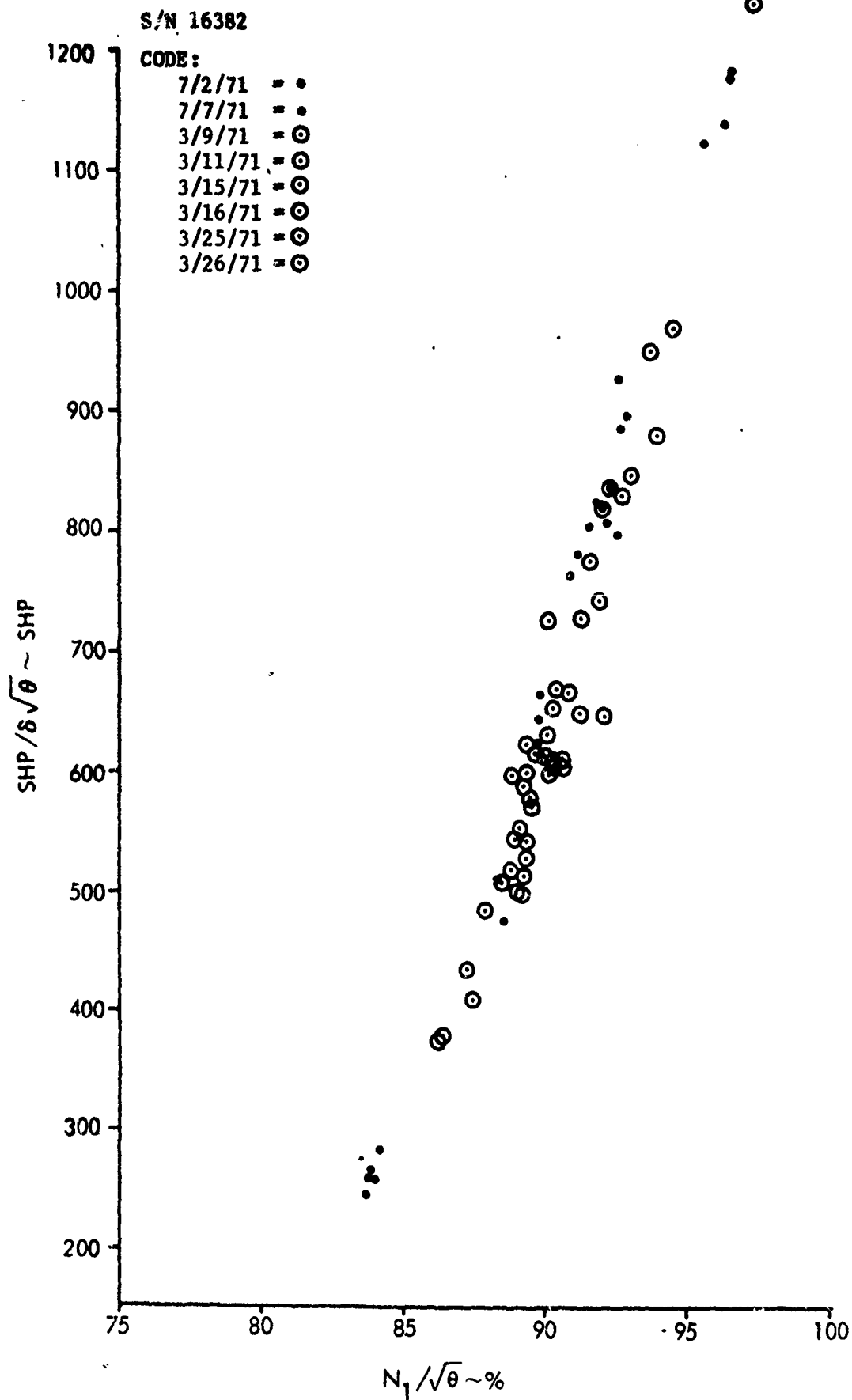


FIGURE 7-125 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

# ENG S/N 18918-BASELINE FLIGHTS

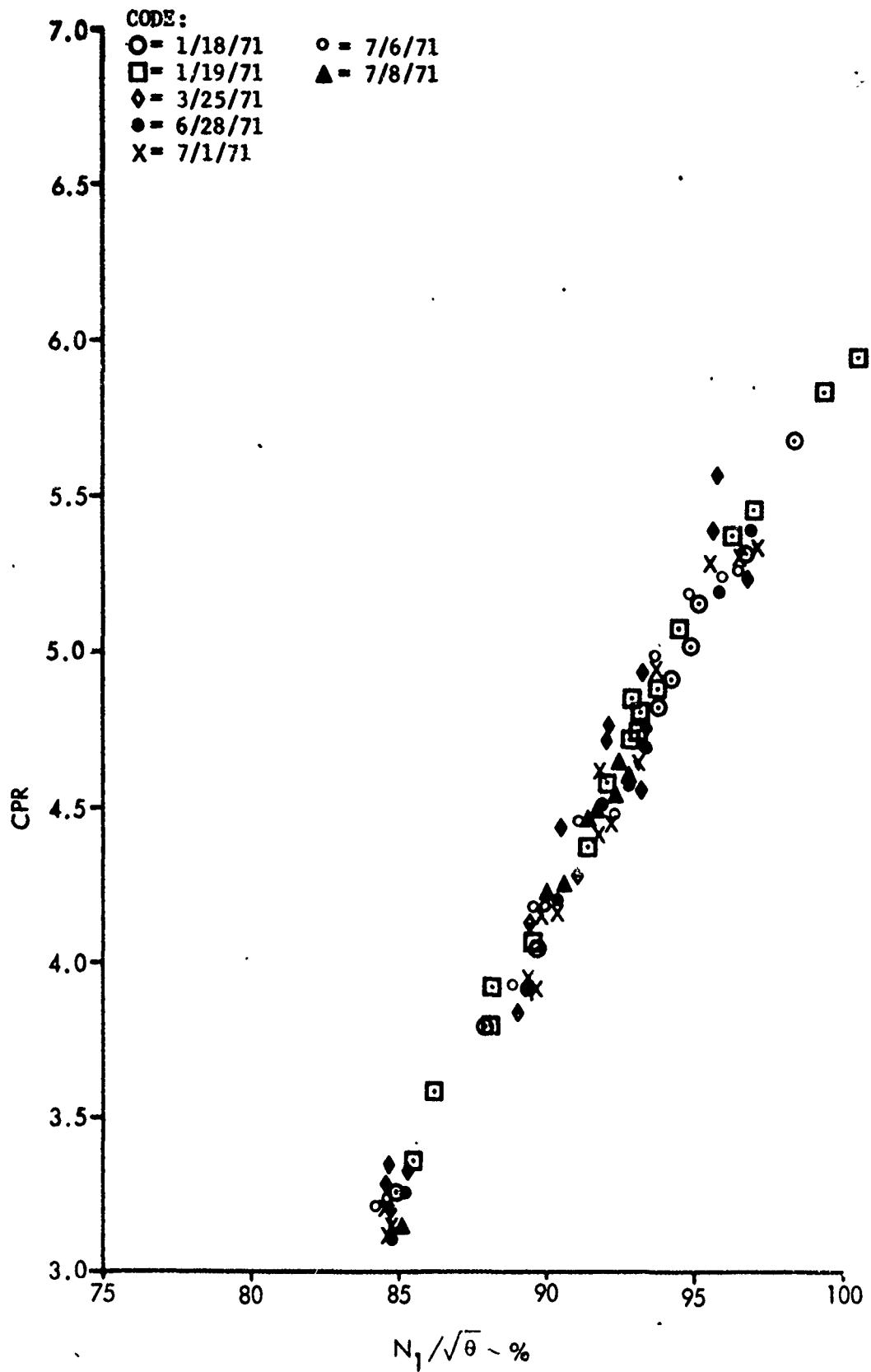


FIGURE 7-126 COMPRESSOR PRESSURE RATIO VS CORRECTED  $N_1$  SPEED

# ENG S/N 18918 - BASELINE FLIGHTS

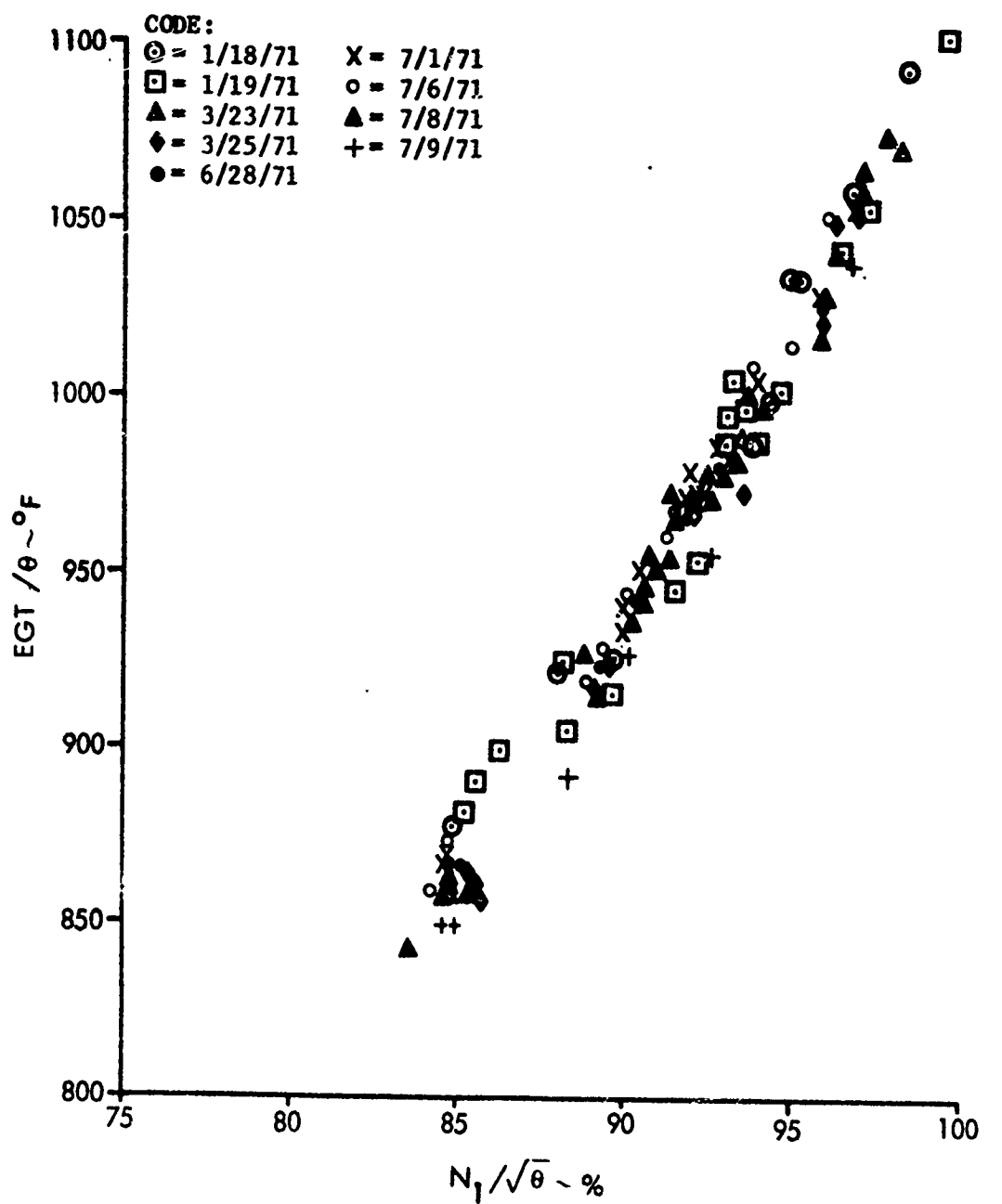


FIGURE 7-127 CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED  $N_1$  SPEED

# ENG S/N 18918-BASELINE FLIGHTS

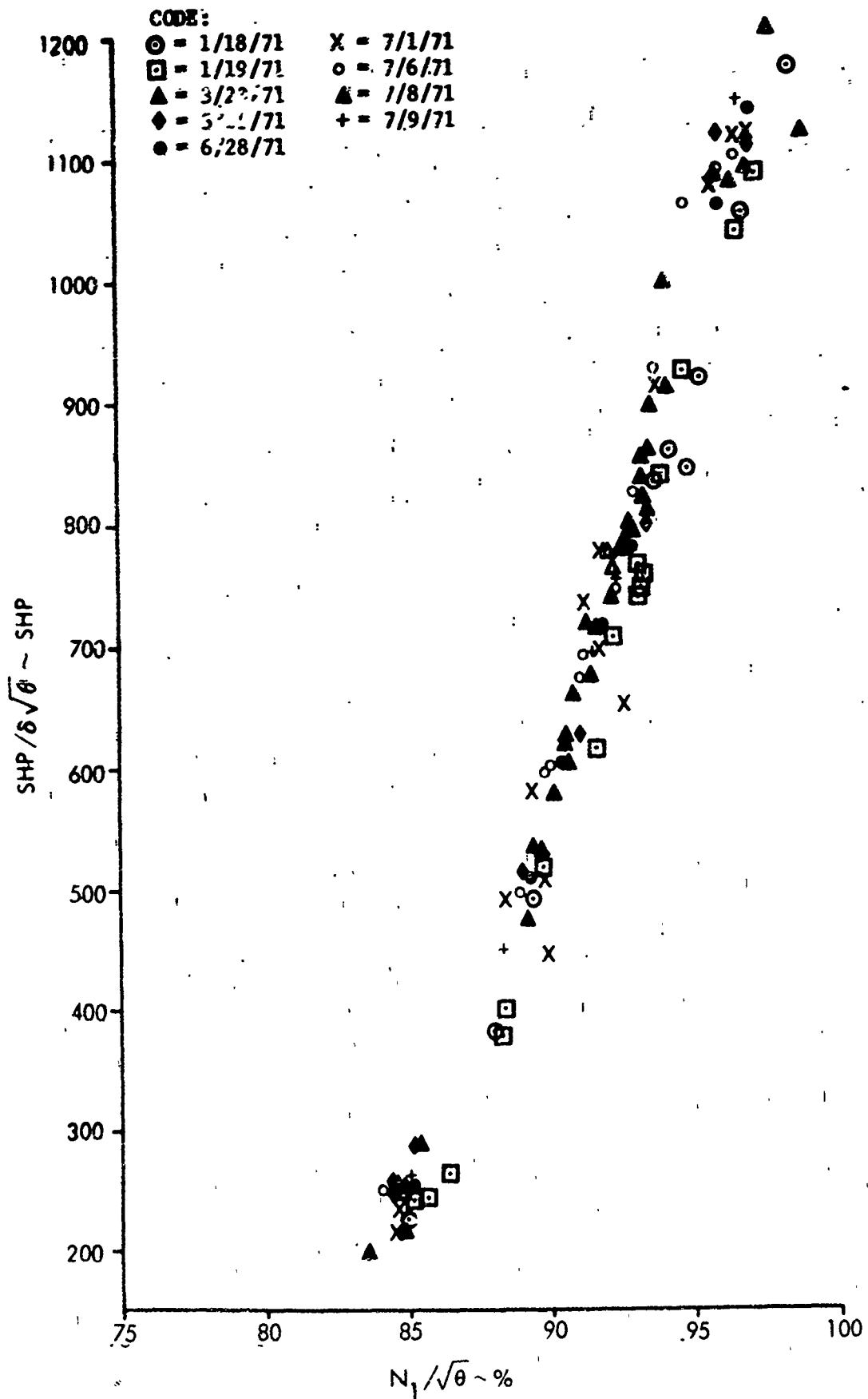


FIGURE 7-128 CORRECTED SHAFT HORSEPOWER VS CORRECTED  $N_1$  SPEED

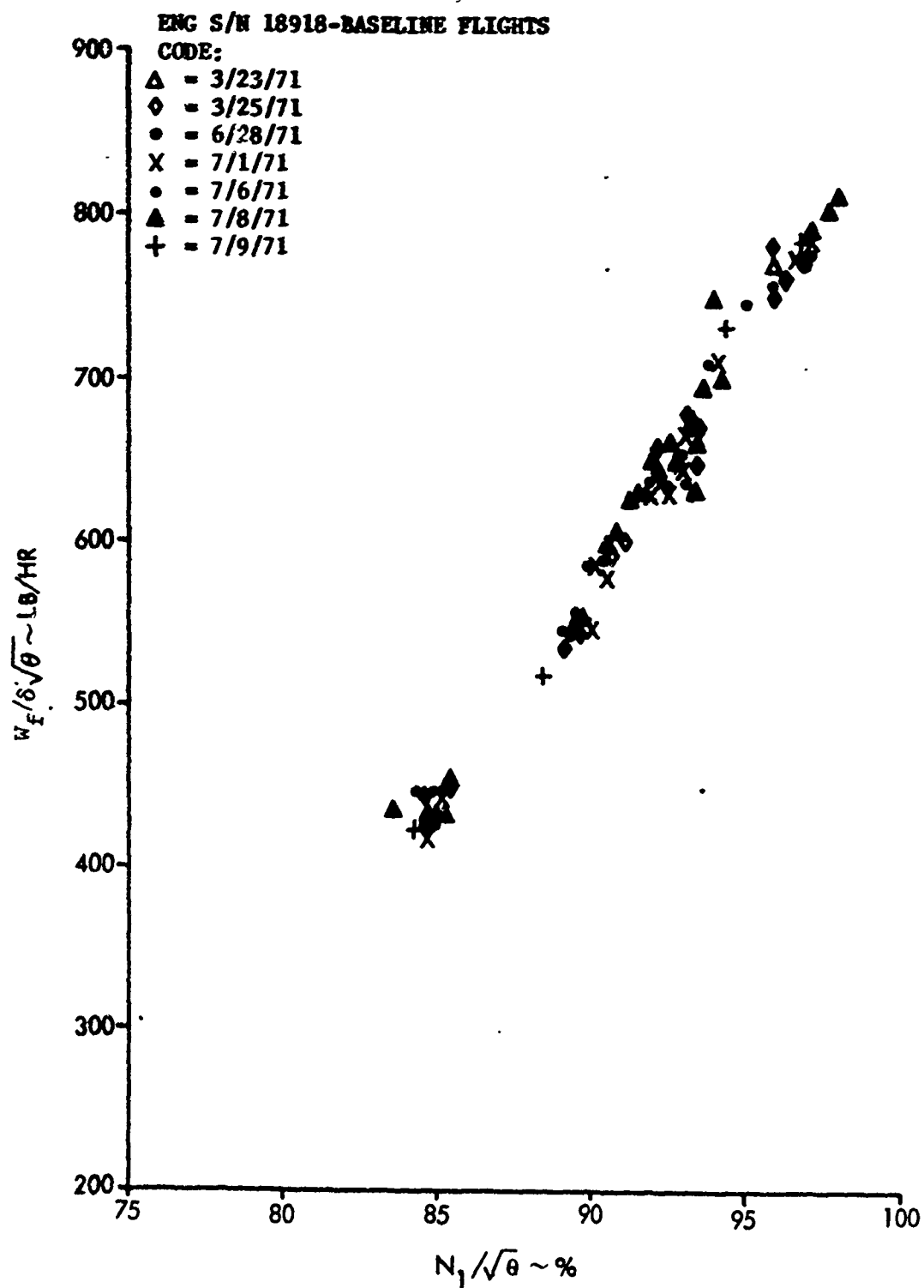


FIGURE 7-129 CORRECTED FUEL FLOW VS CORRECTED  $N_1$  SPEED

# ENG S/N 18918-BASELINE FLIGHTS

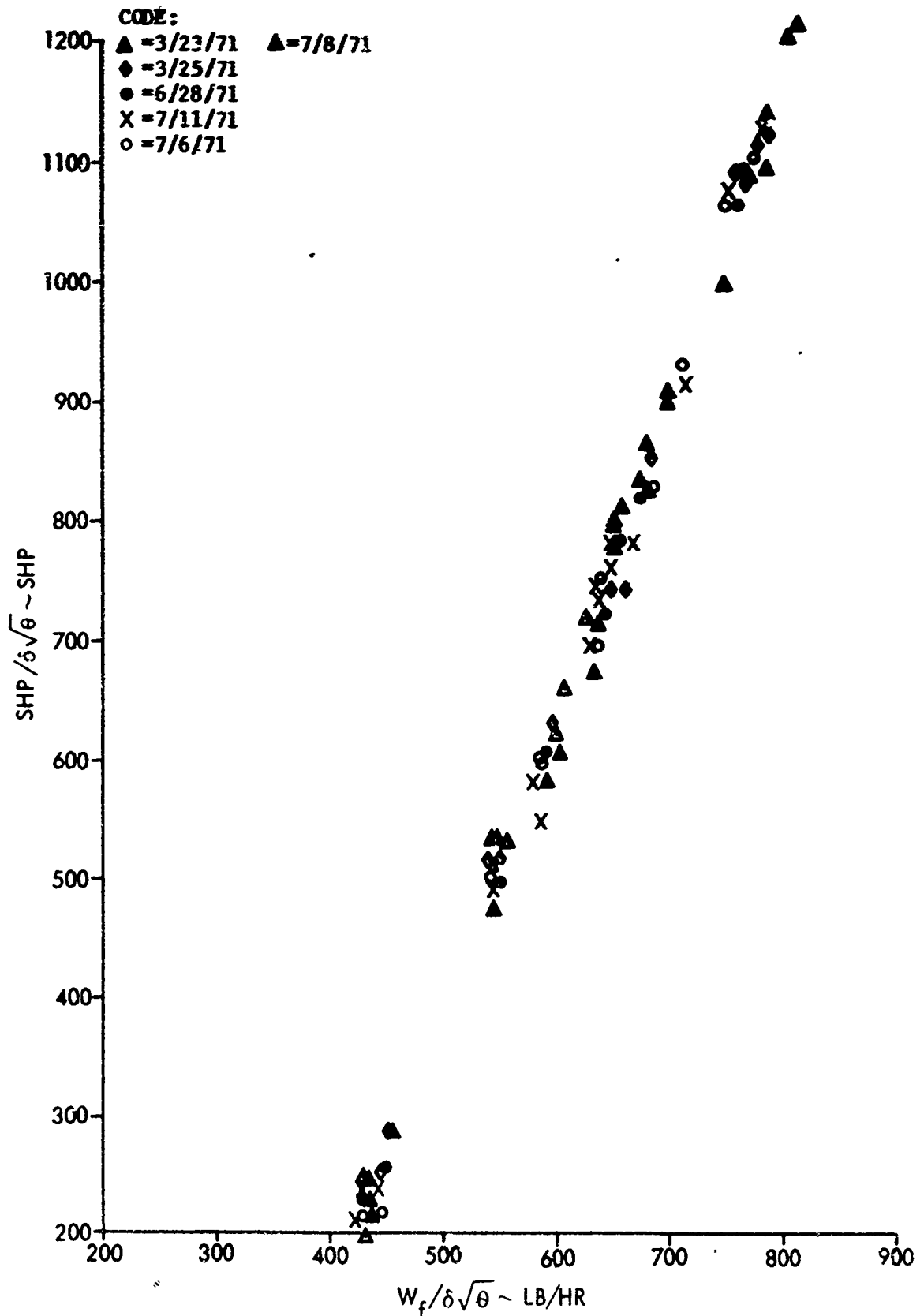


FIGURE 7-130 CORRECTED SHAFT HORSEPOWER VS CORRECTED FUEL FLOW

acceptable limits for a transmitter-indicator combination. The MRS would obviously be consistent in reporting exceedence of stress limits regardless of pilot and transmitter-indicator variations.

$N_2$  overspeed (with  $N_1$  greater than 91 percent) also occurred several times. A different problem was presented in this case. Standard flight procedures permit a pilot to set  $N_2$  to 6,600 RPM under powered conditions. However,  $N_2$  should not exceed 6,640 for more than 3 seconds. Since most pilots fly close to the redline, it is questionable that a pilot can continuously and accurately observe the limit.

- b) Output codes also occurred at various times which were the result of checks performed by the pilot. The checks were the result of test switches or circuit breakers being pulled. A modification to the EU eliminated insignificant codes resulting from caution panel tests and inverter switching.
- c) Droop outputs occurred a few times during the period when NED had made a minor modification to improve the droop detection capability. Experience gained during the program indicated that the time when droop can be measured must be limited to a peculiar set of conditions. Attempting to implement the required mechanization changes during the last stages of the program did not appear advisable.

Accumulated data from the various temperatures and pressures of the engine, transmission, and gearboxes revealed no conclusive trend versus flight hours. In the case of the engine, transmission, and gearboxes, it was not expected that a trend could be observed because the accrued flight time was small compared to TBO's.

## **7.9 VERIFICATION TESTING**

### **7.9.1 PURPOSE AND CONDUCT**

The purpose of verification testing was to evaluate the effectiveness of contractor maintenance monitoring. Evaluation was based upon the diagnosis of LRU's, the condition of which was unknown to the contractor.

Both aircraft 66-17138 and 67-17448 were used to fly six sets of LRU's (3 each) during discrepant parts testing of engines, transmissions, 90° gearboxes and 42° gearboxes. A specific serial numbered LRU may or may not have had an implanted discrepant part.

Selection of discrepant parts used as implants during verification was limited to the types of parts used in previous discrepant parts testing. This limitation permitted the best use of experience gained during previous test phases without the addition of a new dimension by attempting to diagnose a new type of implanted part. LRU's used for verification implants were components which had been overhauled by ARADMAC but had not been used previously on the test bed program. Since baseline information was not available for the verification LRU's, baseline flights for all six sets were flown on aircraft 67-17448 at the conclusion of verification flight tests. Data from the baseline flights were used to see if individual baseline data would change the results of previously submitted verification diagnosis. Tables 7-11 and 7-12 list the discrepant parts for each set of verification LRU's and the serial numbers of LRU's for each flight date.

A teardown and inspection of each component was requested at the conclusion of the verification and baseline testing. The results definitely show that unplanned discrepant parts were included in the verification and baseline tests. In addition, some of the planned discrepant parts, when reexamined, were concluded to be insufficiently degraded to cause any noticeable change in component characteristics.

Engine, 42° and 90° gearbox sets and transmissions tested are discussed in sections 7.9.2 through 7.9.3. For each test set the decisions are stated as

TABLE 7.11 DISCREPANT PART FLIGHT SCHEDULE - VERIFICATION

AIRCRAFT	COMPONENT	SET #1 7/19/71	SET #3 7/26/71	SET #5 8/2 & 3/71
66-17138	Engine	#4 Bearing	No Defect	N <sub>1</sub> Nozzle
	Engine	#2 Bearing	--	#3 Bearing
	Transmission	Mast Bearing	Input Quill	No Defect
	42° Gearbox	Input (Roller)	Input (Ball & Roller)	No Defect
	90° Gearbox	No Defect	Output (Ball)	Input (Ball)
67-17448	Engine Engine Transmission 42° Gearbox 90° Gearbox	SET #2 7/19/71	SET #4 7/22 & 23/71	SET #6 7/30/71
		N <sub>2</sub> Nozzle	No Defect	Compressor
		#2 Bearing	--	--
		T/R Quill (Roller)	No Defect	T/R Quill (Ball)
		No Defect	Input (Ball)	Input (Roller)
		Output (Roller)	Input (Roller)	No Defect

TABLE 7.12 VERIFICATION TEST SCHEDULE

<u>DATE</u>	<u>AIRCRAFT</u>	<u>TEST CONDITION</u>	<u>ENGINE</u>	<u>42° GEARBOX</u>	<u>90° GEARBOX</u>	<u>TRANSMISSION</u>
7/19/71	67-17448	Verification Set 2	18301	A13-9857	B13-5984	A12-3159A
7/19/71	66-17138	Verification Set 1	16886	A13-2148	B12-3295	A12-2541
7/22-23/71	67-17448	Verification Set 4	18270	B13-10078	B13-2339	A12-3159A
7/26/71	66-17138	Verification Set 3	20791	BBB-492	B13-8433	A12-2541
7/30/71	67-17448	Verification Set 6	14819	ABB-564	B13-3176	A12-3159A
8/2-3/71	66-17138	Verification Set 5	17376	B13-9122	B13-9094	A12-2541
8/9-10/71	67-17448	Baseline Set 3	20791	BBB-492	B13-8433	A12-3159A
8/17/71	67-17448	Baseline Set 4	18270	B13-10078	B13-2339	A12-3159A
8/23/71	67-17448	Baseline Set 6	14819	ABB-564	B13-3176	A12-3159A
8/27/71	67-17448	Baseline Set 5	17376	B13-9122	B13-9094	A12-3159A
9/3/71	67-17448	Baseline Set 1	16886	A13-2148	B12-3295	A12-3159A
9/13/71	67-17448	Baseline Set 2	18301	A13-9857	B13-5984	A12-3159A

they were made after a verification test and again after the corresponding baseline test. In most cases, vibration criteria employed during verification tests as well as that employed later in the program for Phase E is presented. The resulting improved identification of the condition of the part is evident. The results discussed are summarized in Tables 7.13 through 7.18 with additional component teardown information.

#### 7.9.2 COMPONENT SET NO. 1 (VERIFICATION CONDITION 1)

Set number 1 of verification components were installed in aircraft 66-17138 flown on July 19, 1971. Results of the verification test are discussed below. In the case of the 42° gearbox, the first verification and baseline diagnosis is based on a preliminary criteria. A revised diagnosis is also presented which represents the results of the more optimum detection scheme.

- Engine - Vibration was marginal, probably resulting from a bearing. Status of the engine should be monitored (if it were in field operation).
- 42° Gearbox - Vibration was excessive, probably as a result of a bearing. The gearbox should be removed and replaced.
- 90° Gearbox - Vibration levels are marginal and should be observed for further degradation.
- Transmission - Vibration levels are within acceptable limits.

The subsequent baseline of this set of components was flown in aircraft 67-17448 on September 3, 1971. Results of the baseline test are as follows:

- Engine - Gas flow performance looked good even though the MRS indicated high fuel consumption (see Figures 7-131 through 7-135). Fuel flow for this engine and one of the others was higher than encountered previously, but is considered to be a normal expansion of the baseline range. Vibration is still excessive. Diagnosis derived during verification does not require revision.

TABLE 7.13 VERIFICATION TEST SUMMARY CHART

## ENGINES

S/N	PLANNED CONDITION	VERIFICATION DIAGNOSIS			REMARKS	BASELINE DIAGNOSIS			REMARKS	RANDOM ANALYSIS	ACTUAL CONDITION (VERIFICATION)	ACTUAL CONDITION (BASELINE)
		MRS PRINTOUT	ENGR PERFORMANCE ANALYSIS	CONCL		MRS PRINTOUT	ENGR PERFORMANCE ANALYSIS	CONCL				
16886 SET 1	#2 BRNG	GOOD	MARGINAL	MARGINAL	TURBINE, PICKUP NOT PART OF VSA MECH. PROVIDED IND. NO CALC. INDICATED	FAULTY	FAULTY	FAULTY	W <sub>1</sub> OUT DUE TO SHIFT OF BASELINE DATA VSA OUTPUT ALSO	PARTIALLY COMPLETE	#1 BRNG (MARGINAL)	#1 BRNG (MARGINAL)
18301 SET 2	N <sub>2</sub> NOZZLE #2 BRNG	FAULTY	FAULTY	FAULTY	ONE VSA OUTPUT 30 MIN. LONG ON PRINTOUT, OTHERS ALSO EXIST. NO CALCULATOR INDICATED	FAULTY	GOOD	GOOD	FREQ. SHIFT OF RANGE RELATED TO N <sub>2</sub> OVERFUELED COLLECTS SYSTEM OUTPUT. NO CALC. INDICATED	PARTIALLY COMPLETE	N <sub>2</sub> NOZZLE (MARGINAL) #2 BRNG (MARGINAL)	GOOD CONDITION
20791 SET 3	NO DEFECT	FAULTY	FAULTY	FAULTY	ONE VSA OUTPUT 45 MIN. LONG ON PRINTOUT, OTHERS EXIST. NO CALC. IND.	FAULTY	FAULTY	FAULTY	ONE 15 MIN. VSA OUTPUT PLUS OTHERS NO CALC. OUTPUT	COMPLETE	TURBINE OUT OF BALANCE COMPRESSOR FOR	TURBINE OUT OF BALANCE COMPRESSOR FOR
18270 SET 4	NO DEFECT	FAULTY	FAULTY	FAULTY	SEVERAL LONG VSA OUTPUTS 15-20 MIN. EACH W <sub>1</sub> OUT OF CALC.	FAULTY	GOOD	GOOD	W <sub>1</sub> CALC. OUTPUT DUE TO SHIFT OF BASELINE DATA VSA OUTPUT RELATED TO N <sub>2</sub> OVERFUELED FREQ. SHIFT	COMPLETE	#1 BRNG #2 BRNG	#1 BRNG #2 BRNG
17376 SET 5	N <sub>1</sub> NOZZLE #3 BRNG	GOOD	MARGINAL	MARGINAL	TURBINE PICKUP NOT PART OF VSA MECH PROVIDED IND. NO CALC. IND.	FAULTY	FAULTY	FAULTY	NOTICEABLE INCREASE IN VSA RATION FLIGHT TO FLIGHT - ONE 15 MIN. VSA OUTPUT NO CALC. IND.	PARTIALLY COMPLETE	N <sub>1</sub> NOZZLE (MARGINAL)	WASPER ADAPTER PLATE
14819 SET 6	COMPRESSOR	FAULTY	FAULTY	FAULTY	ONE VSA OUT OF 35 MIN. OBSERVED OTHERS ALSO NOTED CPE OUT OF CALC. AT 2ND LEVEL	FAULTY	GOOD	GOOD	FREQ. SHIFTS OF RANGE RELATED TO N <sub>2</sub> OVERFUELED COLLECTS SYSTEM OUTPUT. NO CALC. IND.	PARTIALLY COMPLETE	COMPRESSOR	GOOD CONDITION

TABLE 7.14 VERIFICATION TEST SUMMARY CHART

42° GEARBOXES

S/N	PLANNED CONDITION	VERIFICATION DIAGNOSIS*		BASELINE DIAGNOSIS*		RANDOM ANALYSIS	ACTUAL CONDITION (VERIFICATION)	ACTUAL CONDITION (BASELINE)
		ORIGINAL CRITERIA	PHASE E CRITERIA	ORIGINAL CRITERIA	REVISED CRITERIA			
A13 - 2168 SET 1	INPUT (ROLLER)	FAULTY	FAULTY	GOOD	GOOD	PARTIALLY COMPLETE	INPUT (ROLLER) (MARGINAL)	GOOD CONDITION
A13 - 9857 SET 2	NO DEFECT	FAULTY	GOOD	FAULTY	GOOD	COMPLETE	GOOD	GOOD CONDITION
BBB 492 SET 3	INPUT (BALL AND ROLLER)	FAULTY	FAULTY	GOOD	GOOD	PARTIALLY COMPLETE	INPUT (BALL)	GOOD CONDITION
813 - 10078 SET 4	INPUT (BALL)	FAULTY	FAULTY	GOOD	GOOD	PARTIALLY COMPLETE	INPUT (BALL)	GOOD CONDITION
B13 - 9122 SET 5	NO DEFECT	MARGINAL	FAULTY	FAULTY	GOOD	COMPLETE	BRASS AND AL PARTICLES (MARGINAL)	BRASS AND AL PARTICLES (MARGINAL)
ABB - 564 SET 6	INPUT (ROLLER)	GOOD	FAULTY	GOOD	GOOD	PARTIALLY COMPLETE	INPUT (ROLLER)	GOOD CONDITION

\* A REVISION TO CRITERIA EMPLOYED WAS SUGGESTED THROUGHOUT BASELINE TESTS (SEE SECTION 7.9.8).

TABLE 7.15 90° GEARBOX VERIFICATION TEST SUMMARY

S/N	PLANNED CONDITION	VERIFICATION		BASELINE		ACTUAL CONDITION VERIFICATION	ACTUAL CONDITION BASELINE
		ORIGINAL CRITERIA	REVISED CRITERIA	ORIGINAL CRITERIA	REVISED CRITERIA		
B13-3295 SET 1	NO DEFECT	FAULTY	GOOD	FAULTY	GOOD	GOOD	GOOD
B13-5984 SET 2	OUTPUT (ROLLER)	GOOD	FAULTY	GOOD	GOOD	OUTPUT (ROLLER)	GOOD
B13-8433 SET 3	OUTPUT (BALL)	MARGINAL	GOOD	FAULTY	FAULTY	GOOD	GOOD
B13-2339 SET 4	INPUT (ROLLER)	GOOD	FAULTY	GOOD	FAULTY	MARGINAL INPUT ROLLER	GOOD
B13-9094 SET 5	INPUT (BALL)	FAULTY	FAULTY	MARGINAL	GOOD	GOOD	GOOD
B13-3176 SET 6	NO DEFECT	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD

TABLE 7.16 TRANSMISSION VERIFICATION TEST SUMMARY

S/N	PLANNED CONDITION	VERIFICATION		BASELINE		ACTUAL CONDITION VERIFICATION	ACTUAL CONDITION BASELINE
		ORIGINAL CRITERIA	REVISED CRITERIA	ORIGINAL CRITERIA	REVISED CRITERIA		
A12-2541 SET 1	MAST BEARING	GOOD	GOOD	MARGINAL	GOOD	GOOD	GOOD
A12-2541 SET 2	INPUT QUILL	MARGINAL	GOOD	MARGINAL	GOOD	GOOD	GOOD
A12-3159A SET 3	T/R QUILL (ROLLER)	MARGINAL	GOOD	MARGINAL	GOOD	T/R QUILL MARGINAL	GOOD
A12-3159A SET 4	T/R QUILL (BALL)	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
A12-3159A SET 5	NO DEFECT	GOOD	GOOD	MARGINAL	GOOD	GOOD	GOOD
A12-2541 SET 6	NO DEFECT	FAULTY	GOOD	FAULTY	GOOD	GOOD	GOOD

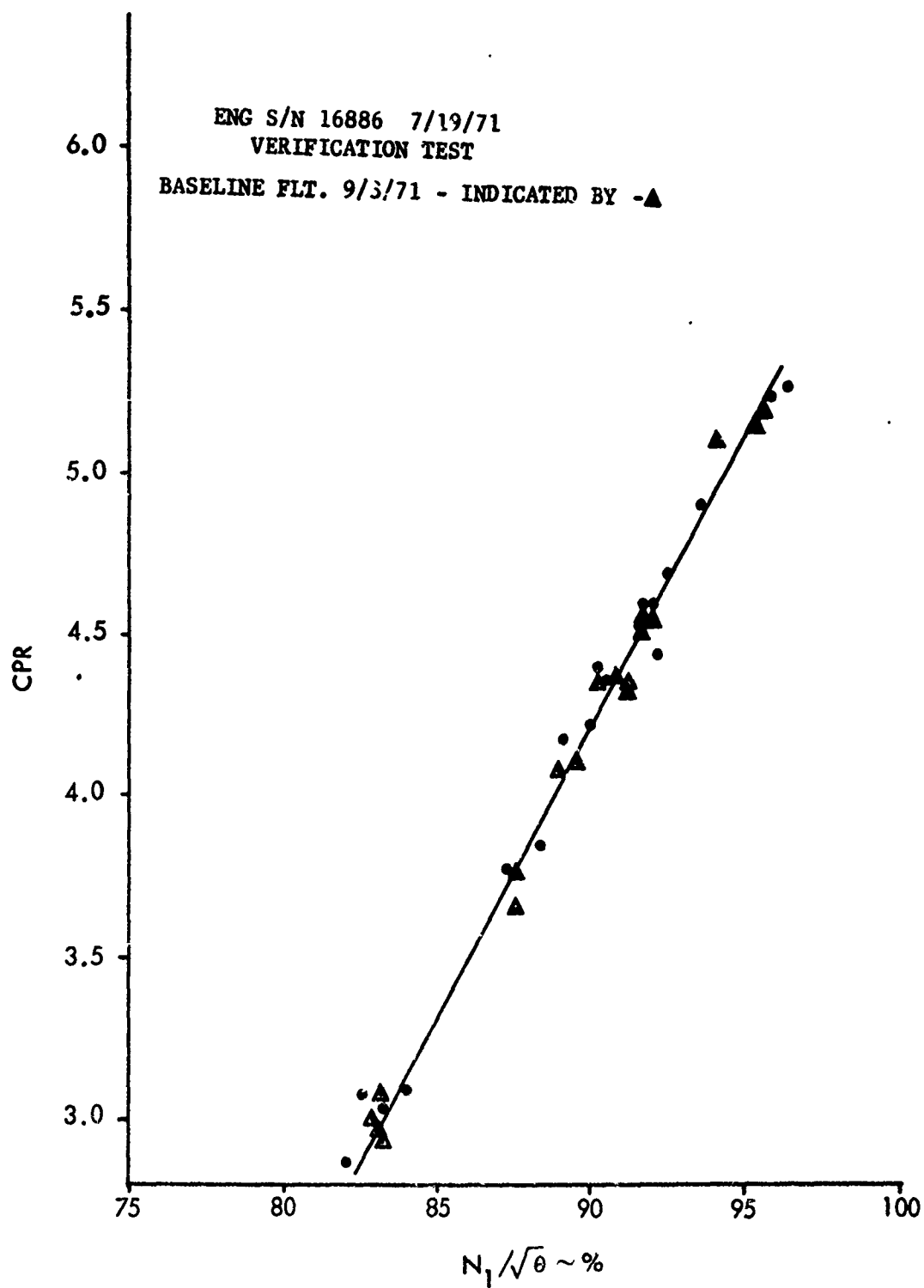


FIGURE 7-131 COMPRESSOR PRESSURE RATIO  
VS  
CORRECTED  $N_1$  SPEED

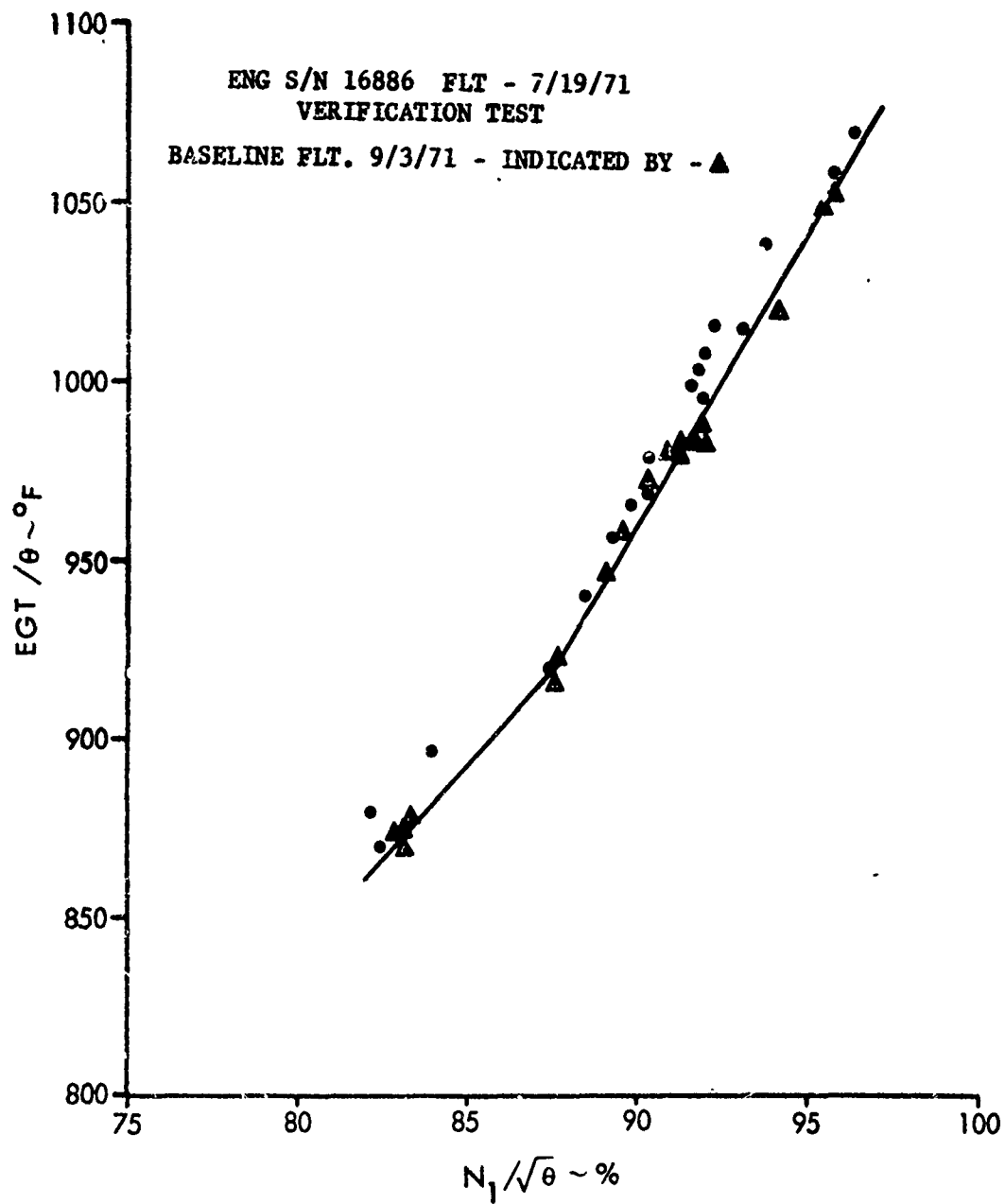


FIGURE 7-132 CORRECTED EXHAUST GAS TEMPERATURE  
VS  
CORRECTED  $N_1$  SPEED

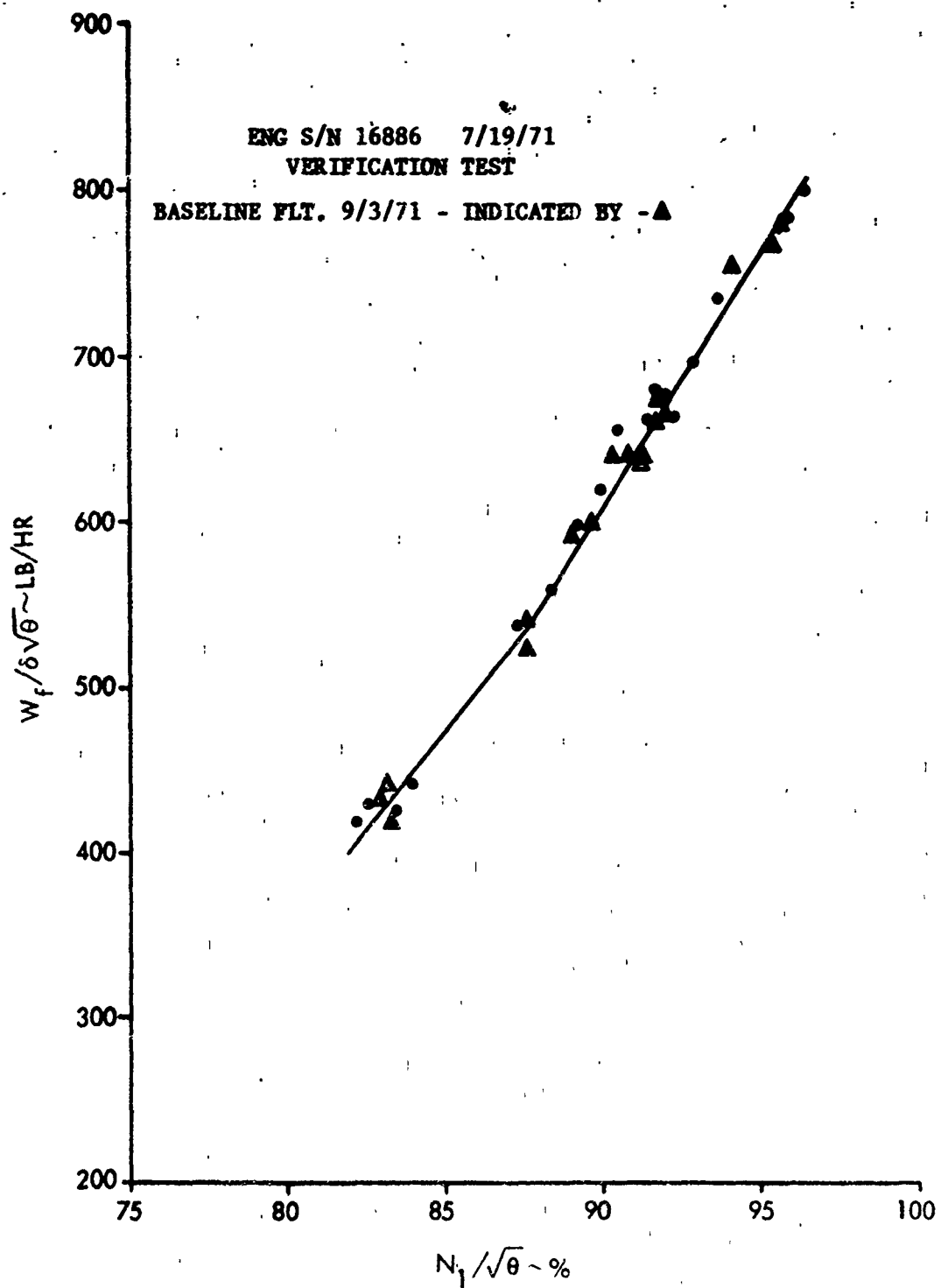


FIGURE 7-133 CORRECTED FUEL FLOW  
 VS  
 CORRECTED  $N_1$  SPEED

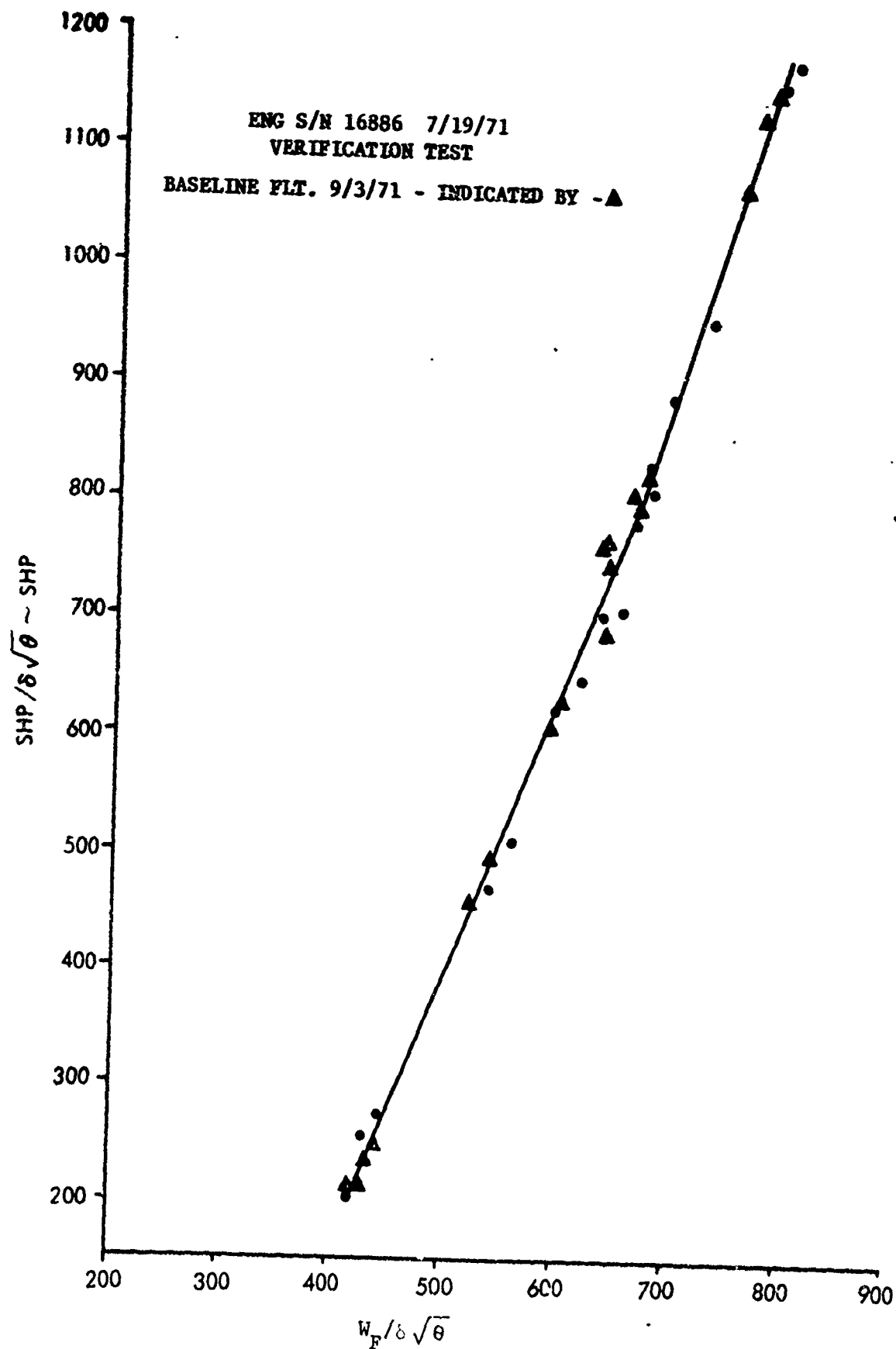


FIGURE 7-134 CORRECTED SHAFT HORSEPOWER  
VS  
CORRECTED FUEL FLOW

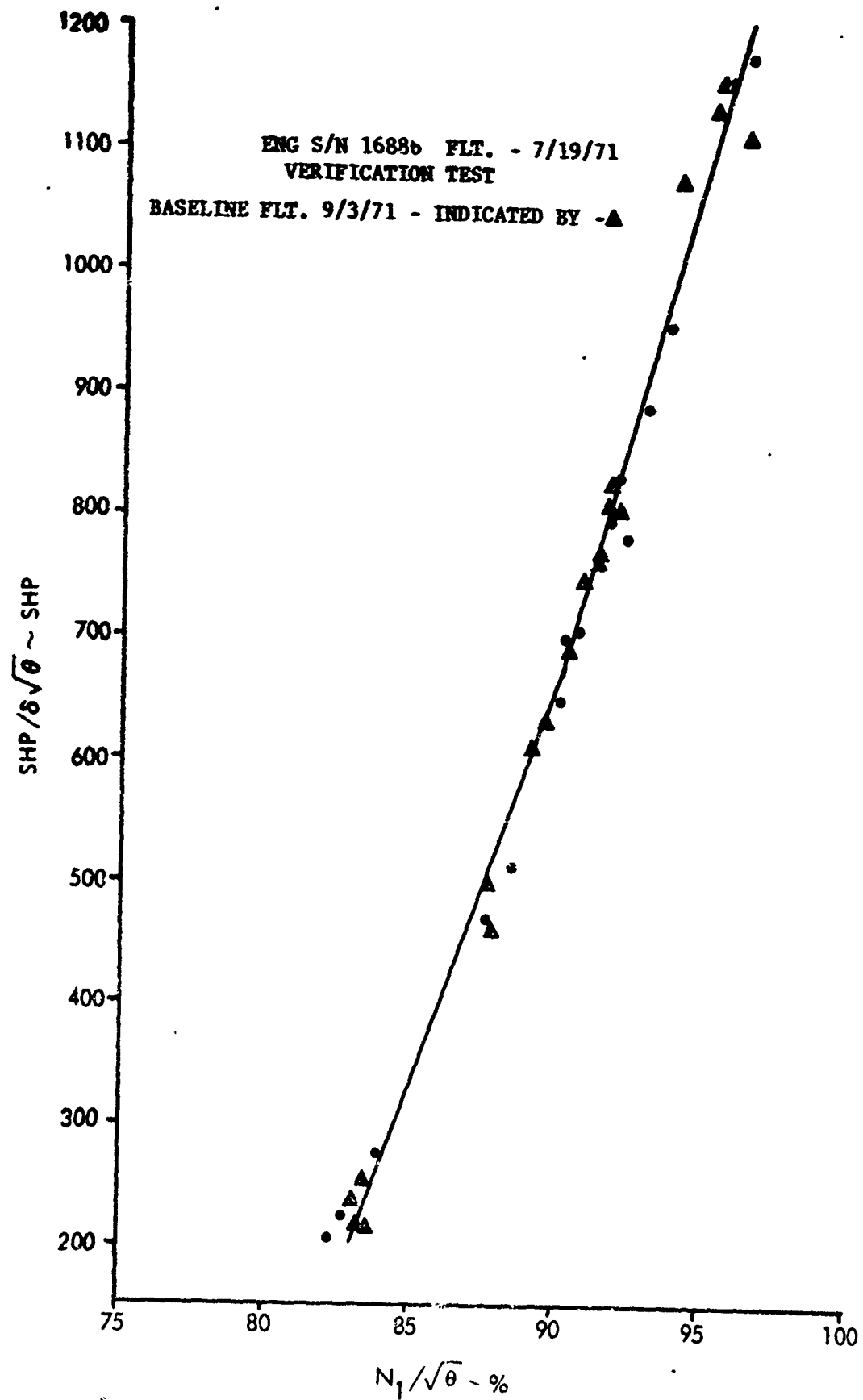


FIGURE 7-135 CORRECTED SHAFT HORSEPOWER  
VS  
CORRECTED  $N_1$  SPEED

42° Gearbox - The MRS indicated excessive vibration and analysis confirmed the output. The diagnosis derived during verification does not require revision. An improved criteria will be developed when additional baseline information is available.

Using the readjusted criteria for the 42° gearbox, the vibration levels indicated a bad gearbox during verification and a good gearbox during baseline. A discussion of the new 42° gearbox criteria is in Section 7.9.8.

90° Gearbox - Vibration levels are within acceptable limits.

Transmission - Threshold levels for vibration criteria are very near the limit. The component is marginal.

### 7.9.3 COMPONENT SET NO. 2 (VERIFICATION CONDITION 2)

Set number 2 of verification components were installed in aircraft 67-17448 flown on July 19, 1971. Results of the verification test are as follows:

Engine - Vibration levels were excessive, indicating the engine should be removed and replaced.

42° Gearbox - Vibration levels were excessive.

90° Gearbox - The component is not discrepant. Vibration levels are within tolerance.

Transmission - Vibration characteristics indicate that this component is operating in a condition that will approach discrepancy. It is currently marginal.

Baseline of this set of components was obtained from flight of aircraft 67-17448 on September 13, 1971. Results of the baseline test are as follows:

Engine - No indications of degraded conditions were evident. Engine was good (see Figures 7-138 through 7-142 for a comparison of verification and baseline gas flow performance). No change is required to the previous verification diagnosis.

42° Gearbox - Vibration levels were as high as those during verification. This gearbox appears to be discrepant even though it is not supposed to be defective. The verification diagnosis does not require revision.

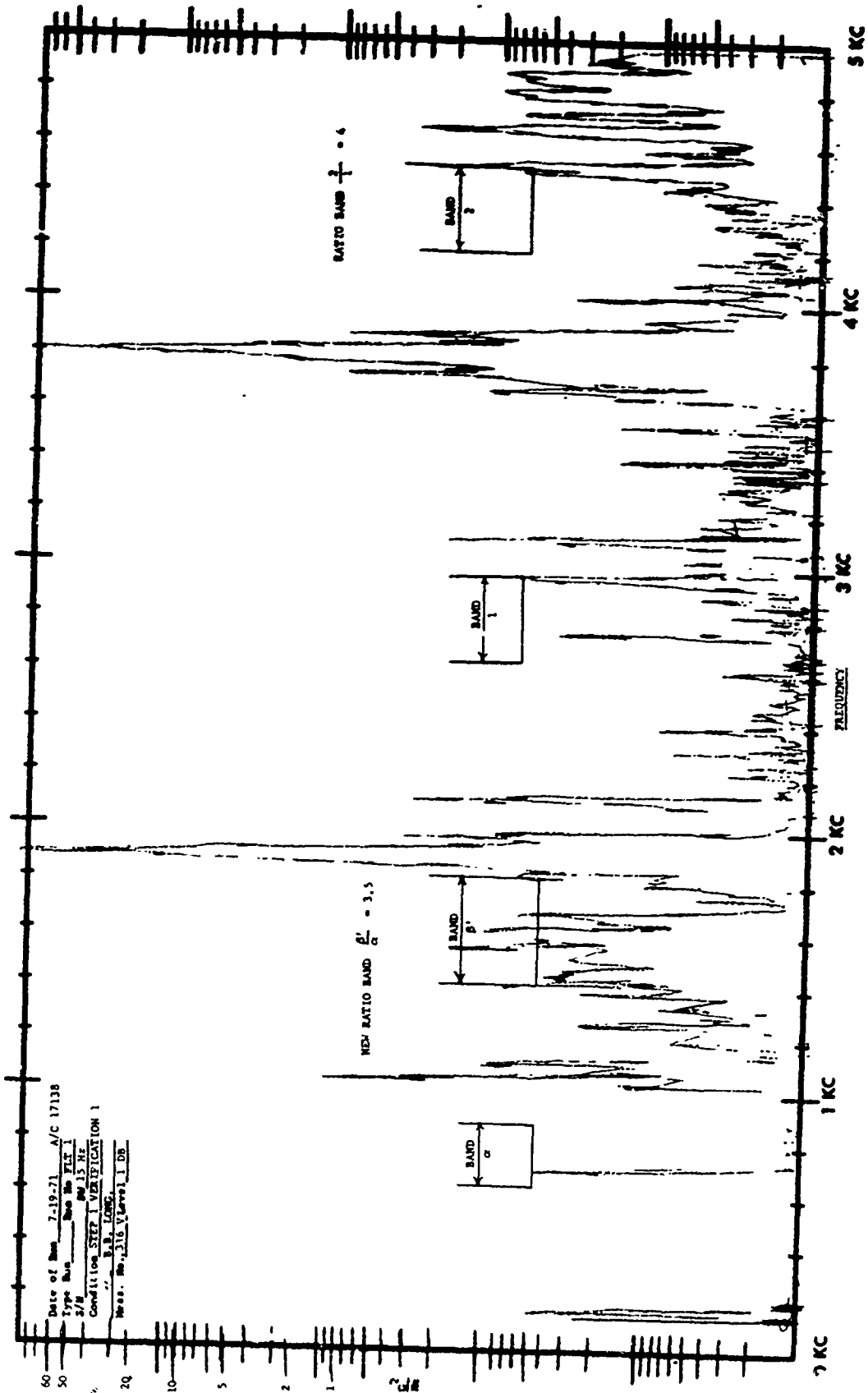


FIGURE 7-136 42° GEARBOX LONGITUDINAL, 7/19/71,  
A/C 17138, STEP 1, VERIFICATION 1

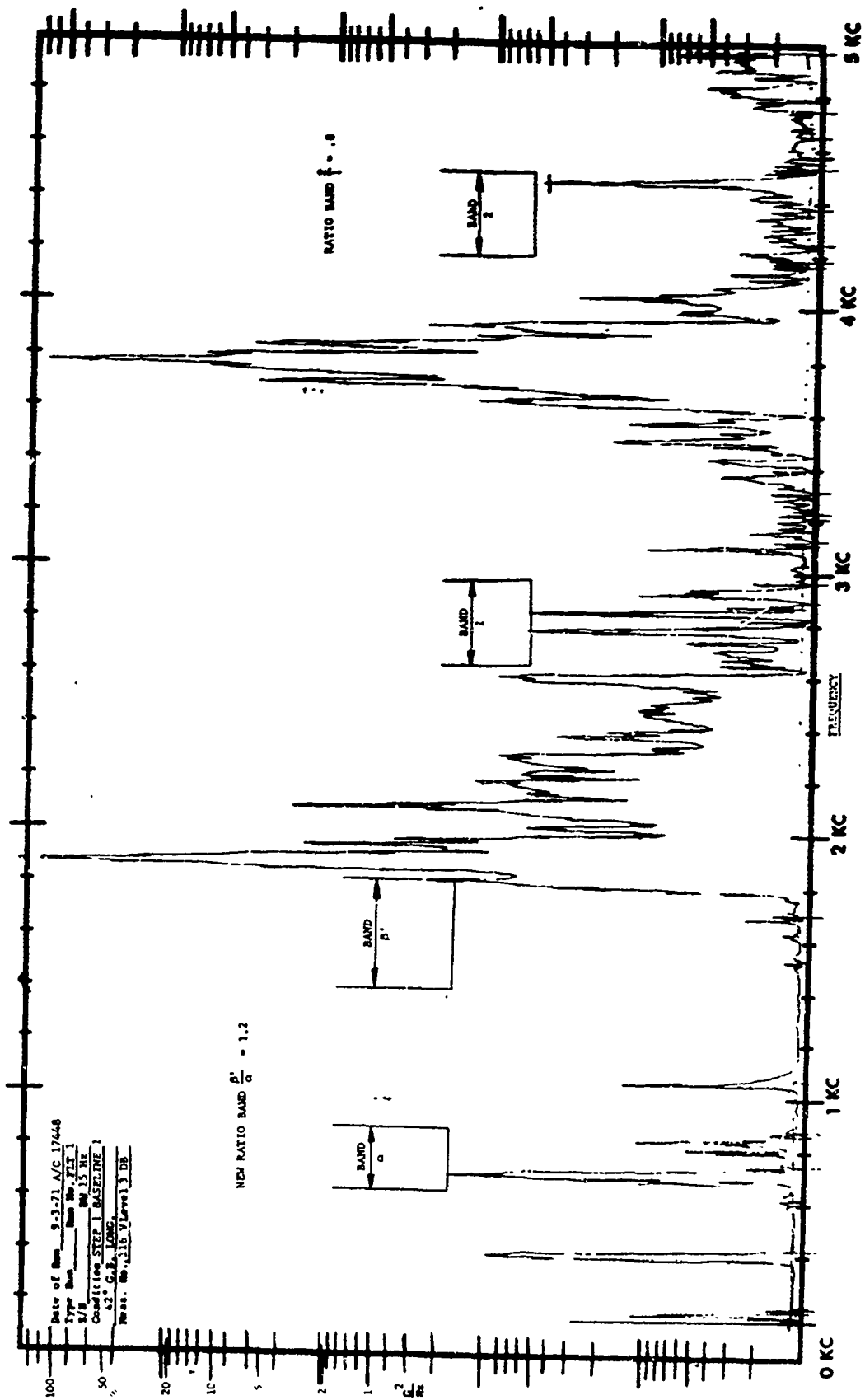


FIGURE 7-137 42° GEARBOX LONGITUDINAL, 9/3/71  
 A/C 17448, STEP 1, BASELINE 1

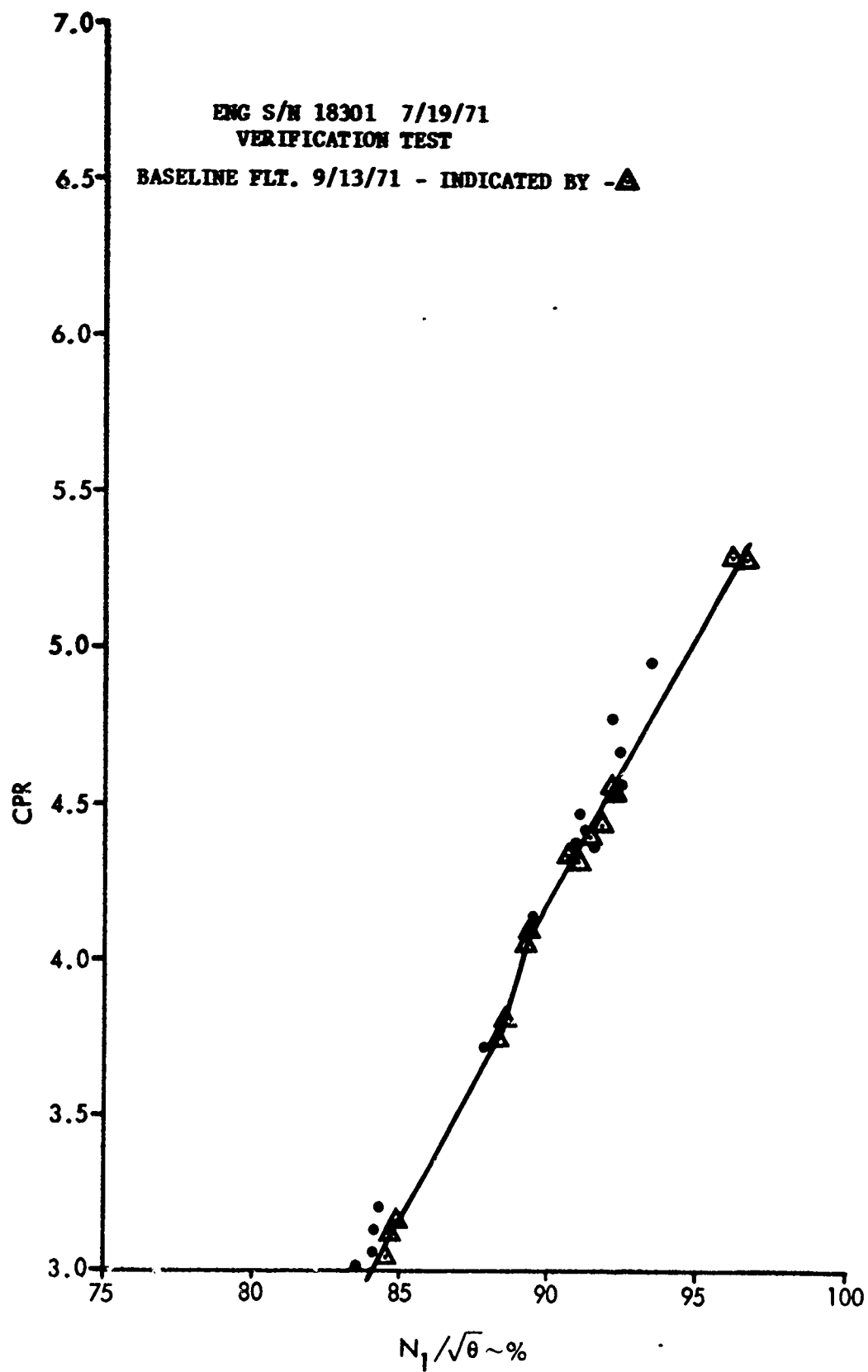


FIGURE 7-138 COMPRESSOR PRESSURE RATIO  
VS  
CORRECTED  $N_1$  SPEED

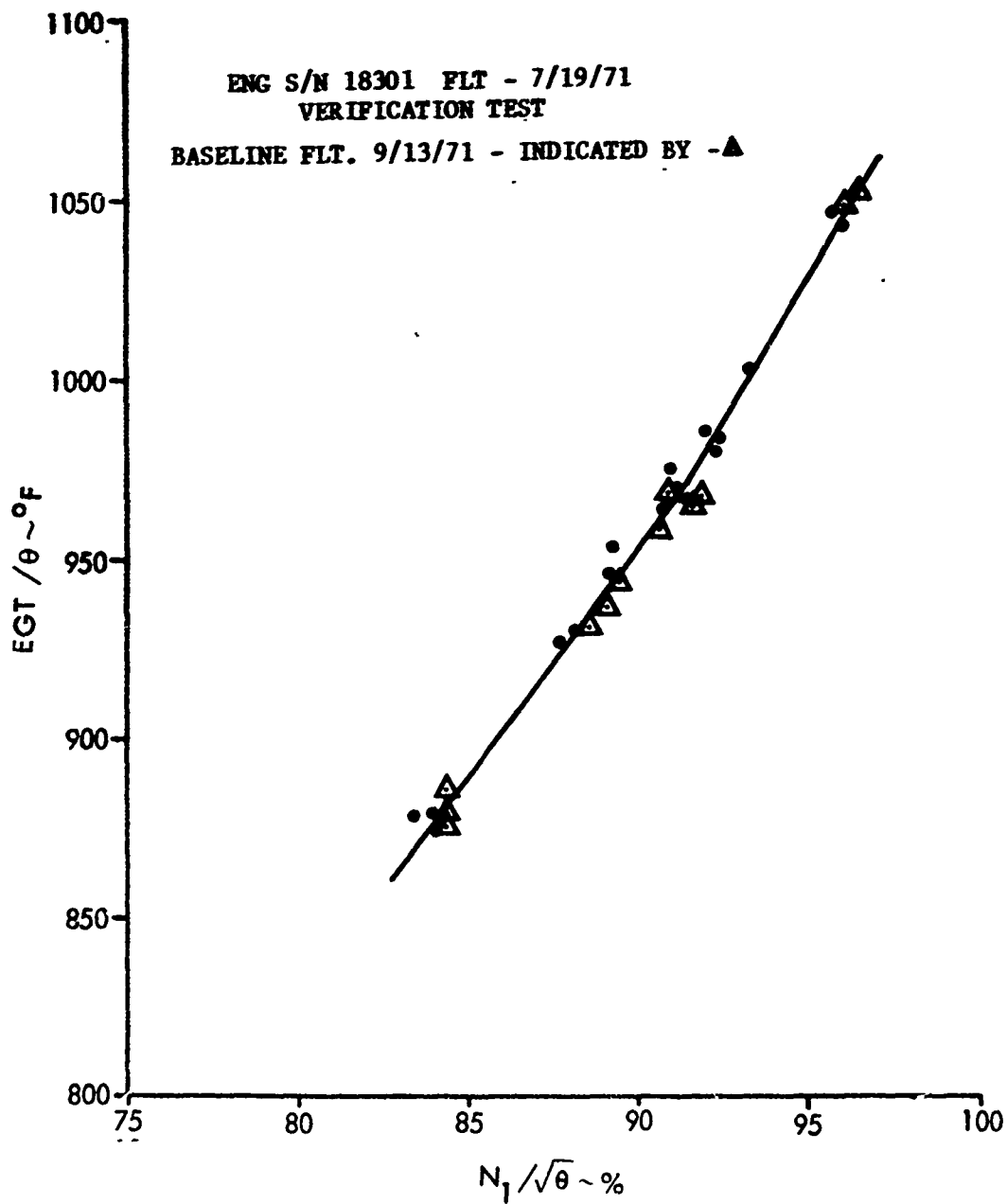


FIGURE 7-139 CORRECTED EXHAUST GAS TEMPERATURE  
VS  
CORRECTED  $N_1$  SPEED

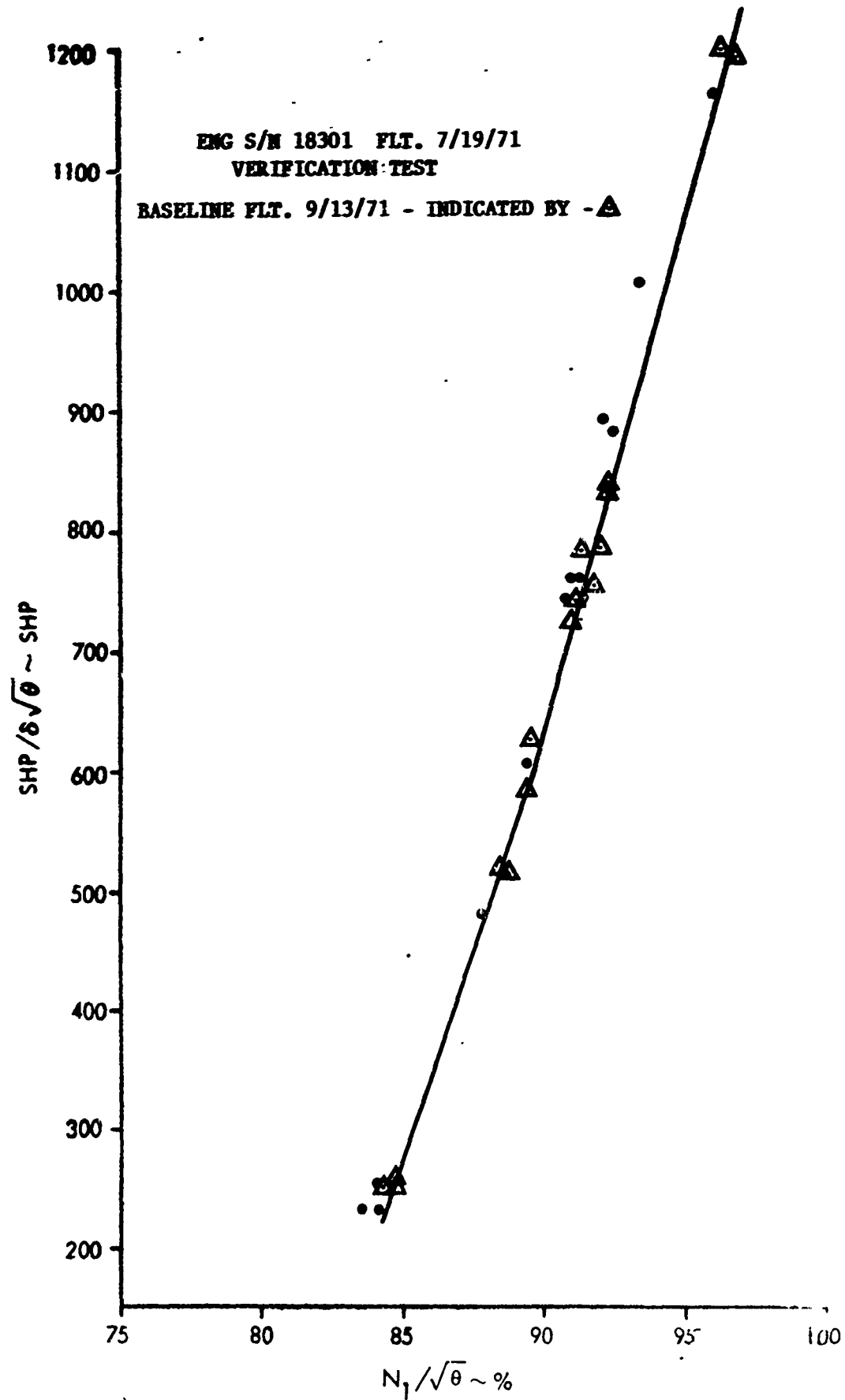


FIGURE 7-140 CORRECTED SHAFT HORSEPOWER  
 VS  
 CORRECTED  $N_1$  SPEED

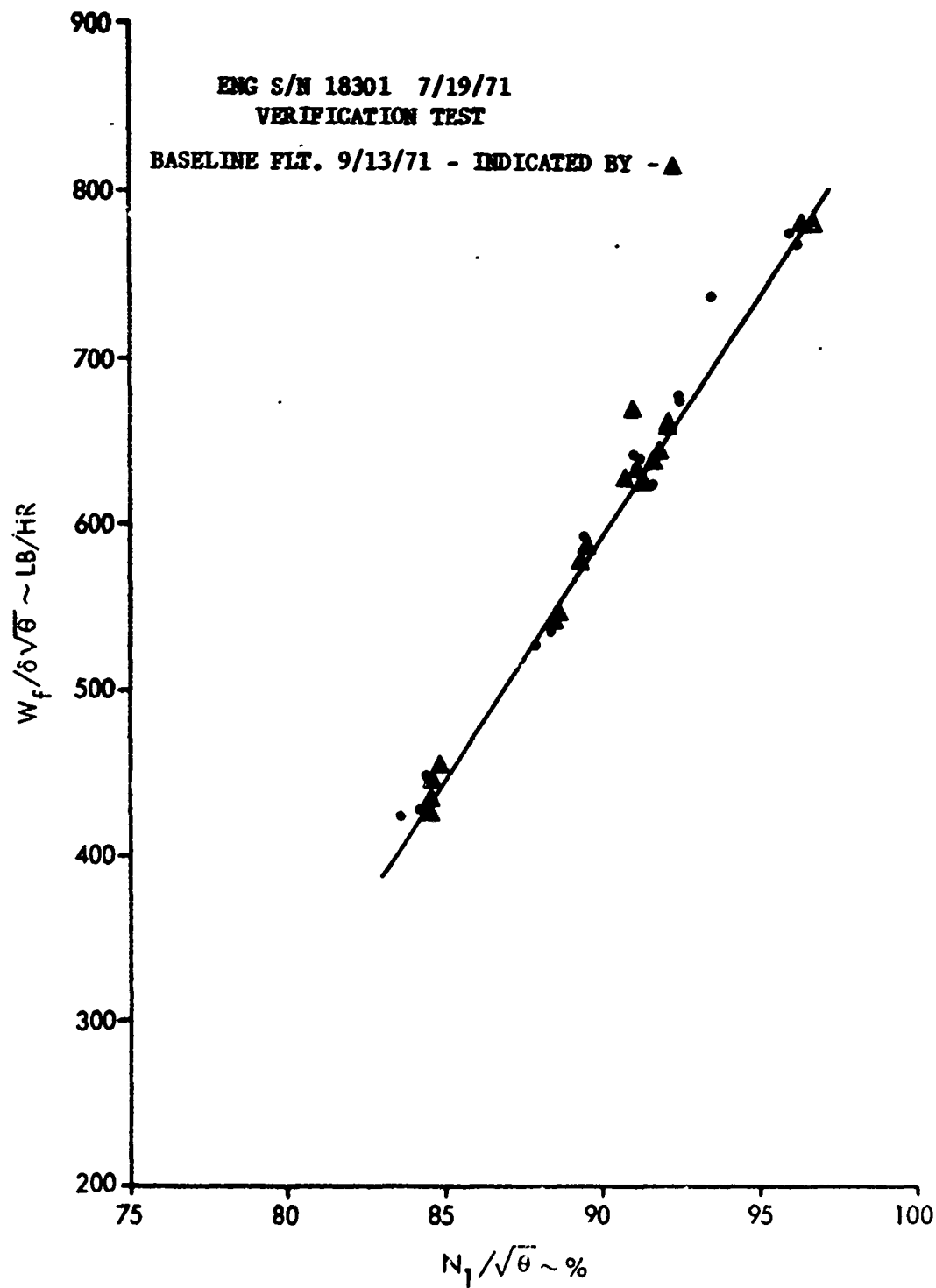


FIGURE 7-141 CORRECTED FUEL FLOW .  
VS  
CORRECTED  $N_1$  SPEED

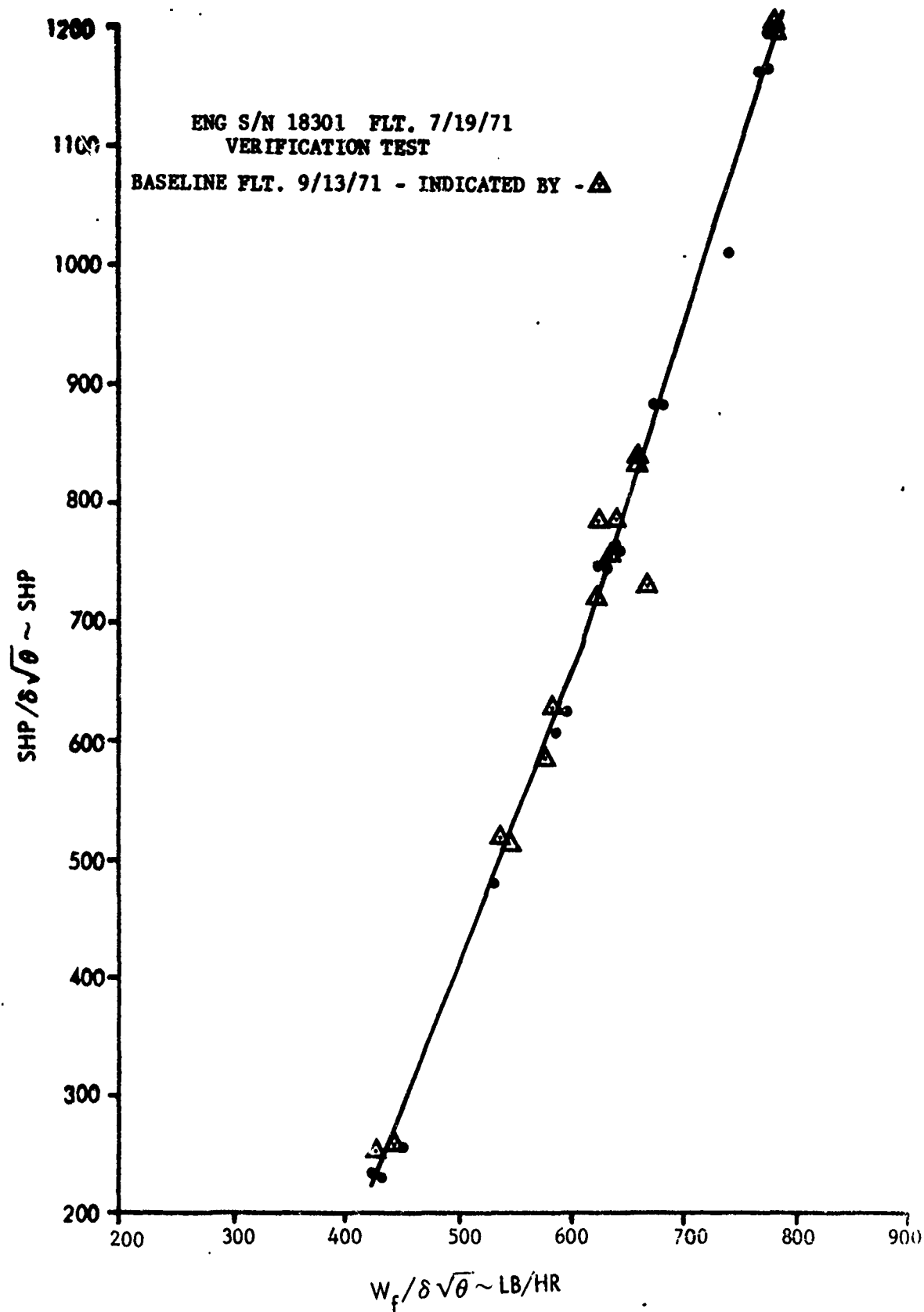


FIGURE 7-142 CORRECTED SHAFT HORSEPOWER  
VS  
CORRECTED FUEL FLOW

90° Gearbox - Vibration levels are excessive.

Transmission - Vibration levels are marginal and should be observed for further degradation.

The readjusted criteria for the 42° gearbox revises the original diagnosis. Vibration level from both the verification and baseline flights indicates the gearbox is good.

#### 7.9.4 COMPONENT SET NO. 3 (VERIFICATION CONDITION 3)

Set number 3 of verification components were installed in aircraft 17138 and flown on July 26, 1971. Results of the verification test are as follows:

Engine - Vibration levels are excessive and are probably caused by a degraded bearing. The engine should be removed and replaced.

42° Gearbox - Vibration levels indicate that the gearbox is degraded. It should be removed and replaced.

90° Gearbox - Vibration criteria indicates that the component is marginal.

Transmission - Vibration levels indicate that the component is marginal.

Baseline of this set of components was flown in aircraft 17448 on August 9, 1971 and August 10, 1971. Results of the baseline test are as follows:

Engine - Vibration is still excessive. Levels are higher than those encountered on other baselines tested during the program. This engine is definitely discrepant. Previous verification diagnosis does not require revision.

42° Gearbox - Even though an MRS printout indicates a vibration problem, analysis of data from both flights indicates the gearbox is a good component. No change to verification diagnosis is required.

Applying the readjusted criteria to the 42° gearbox vibration data indicated a faulty verification gearbox which should be removed and replaced. The same criteria indicated a good gearbox during the baseline test.

90° Gearbox - Vibration levels indicate that the gearbox is degraded.

Transmission - Vibration levels indicate that the component is marginal.

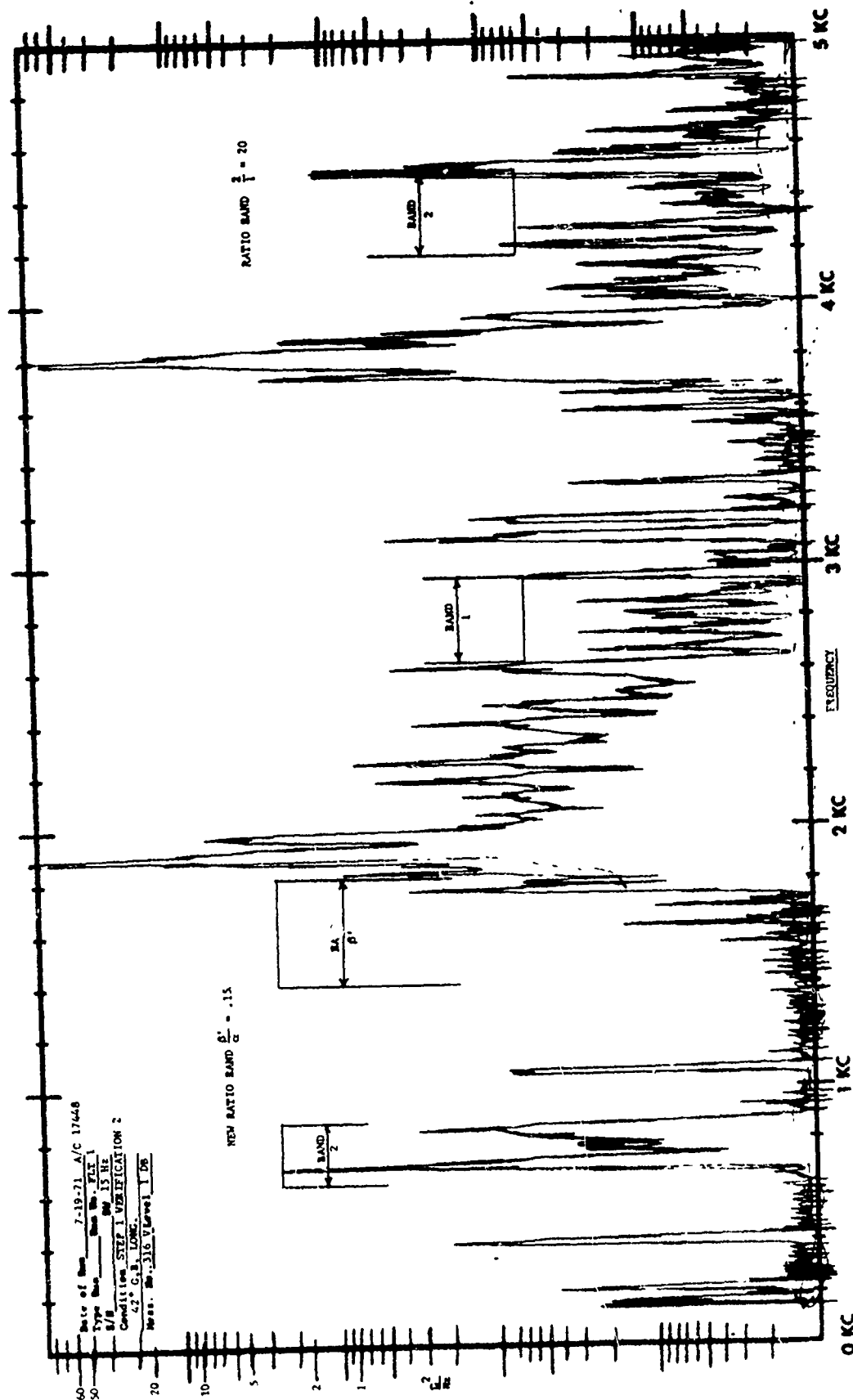


FIGURE 7-143 42° GEARBOX LONGITUDINAL, 7/19/71  
A/C 17448, STEP 1, VERIFICATION 2

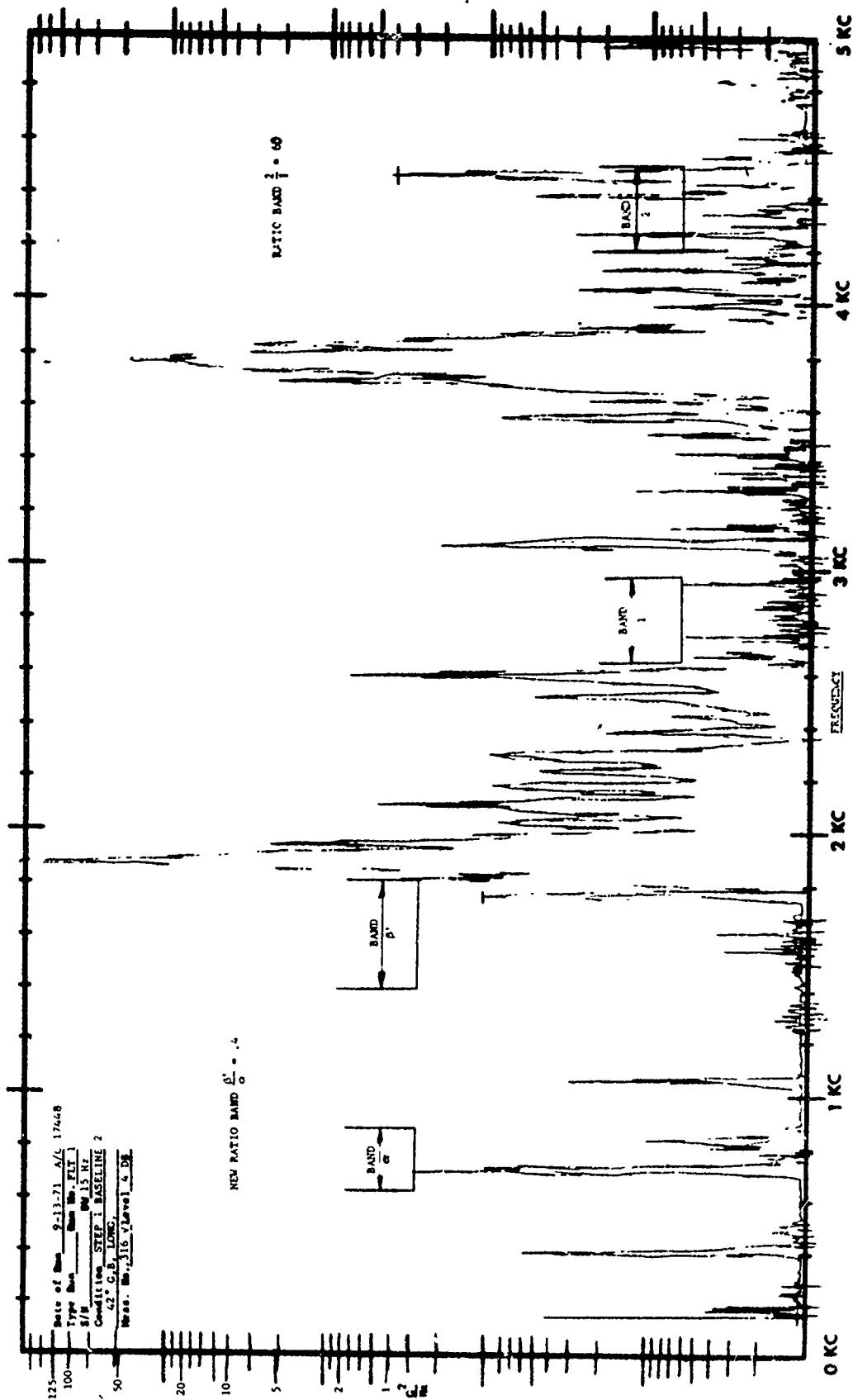


FIGURE 7-144 42° GEARBOX LONGITUDINAL, 9/13/71  
A/C 17448, STEP 1, BASELINE 2

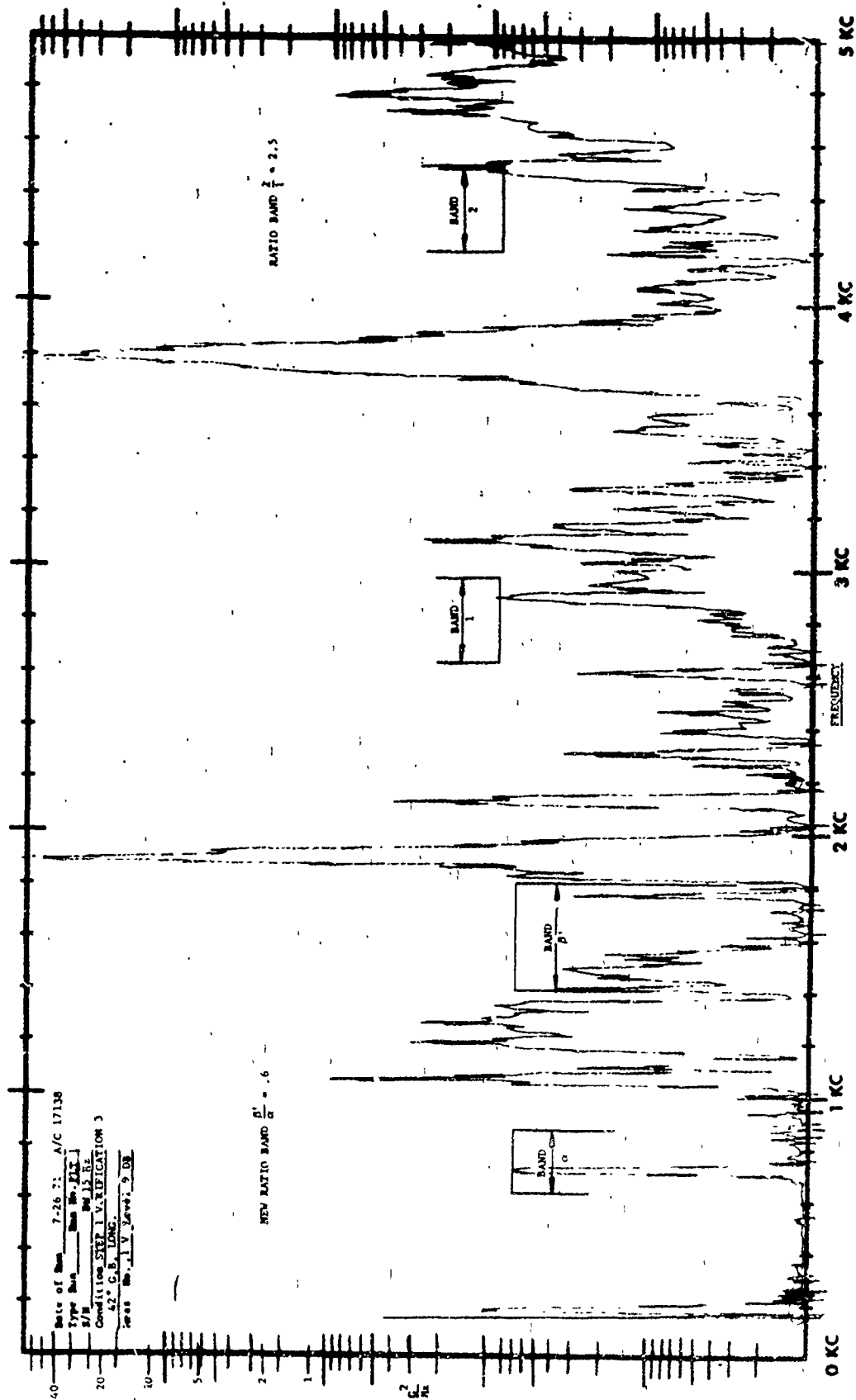


FIGURE 7-145 42° GEARBOX LONGITUDINAL, 7/26/71  
A/C 17138, STEP 1, VERIFICATION 3

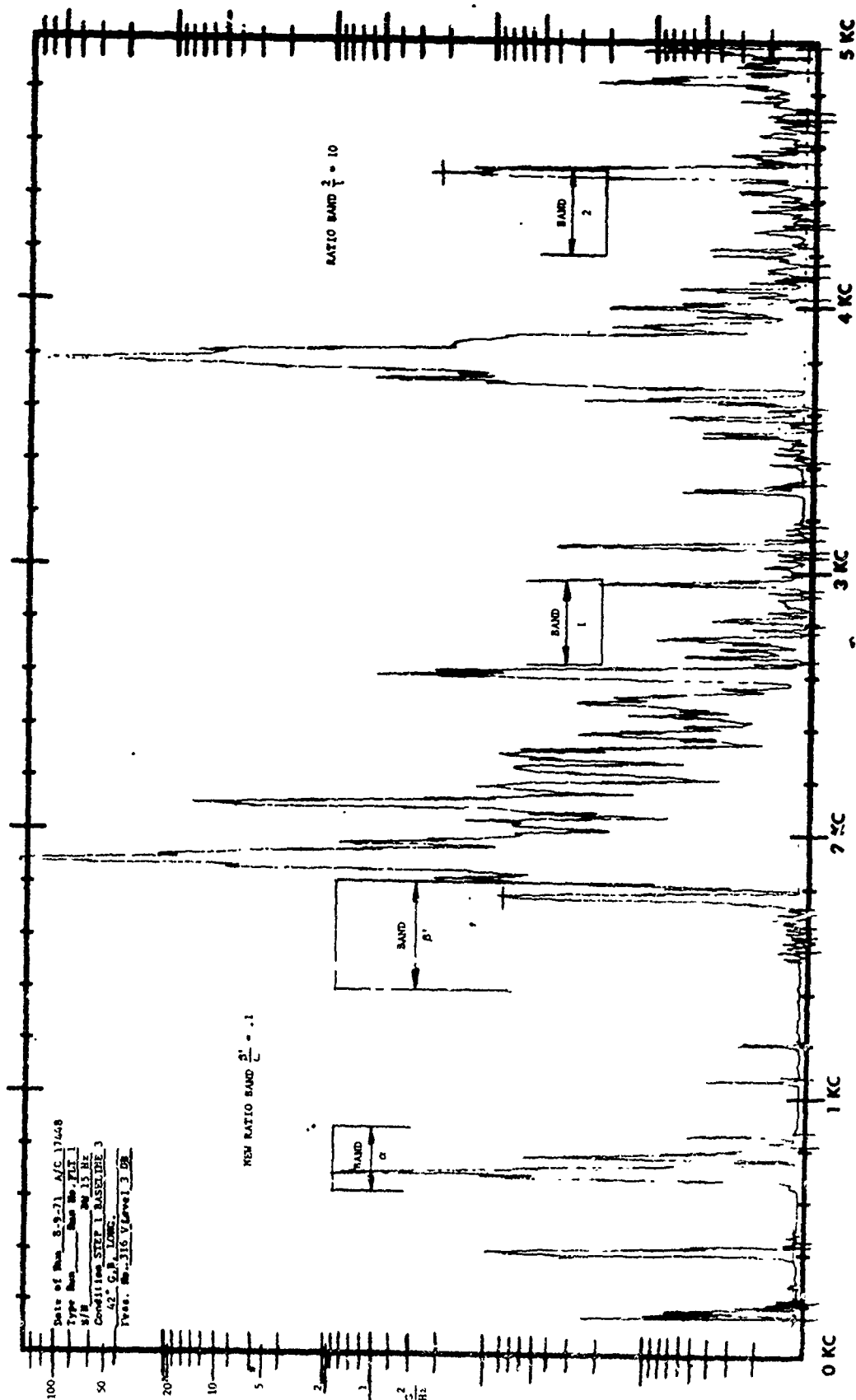


FIGURE 7-146 42° GEARBOX LONGITUDINAL, 8/9/71  
A/C 17448, STEP 1, BASELINE 3

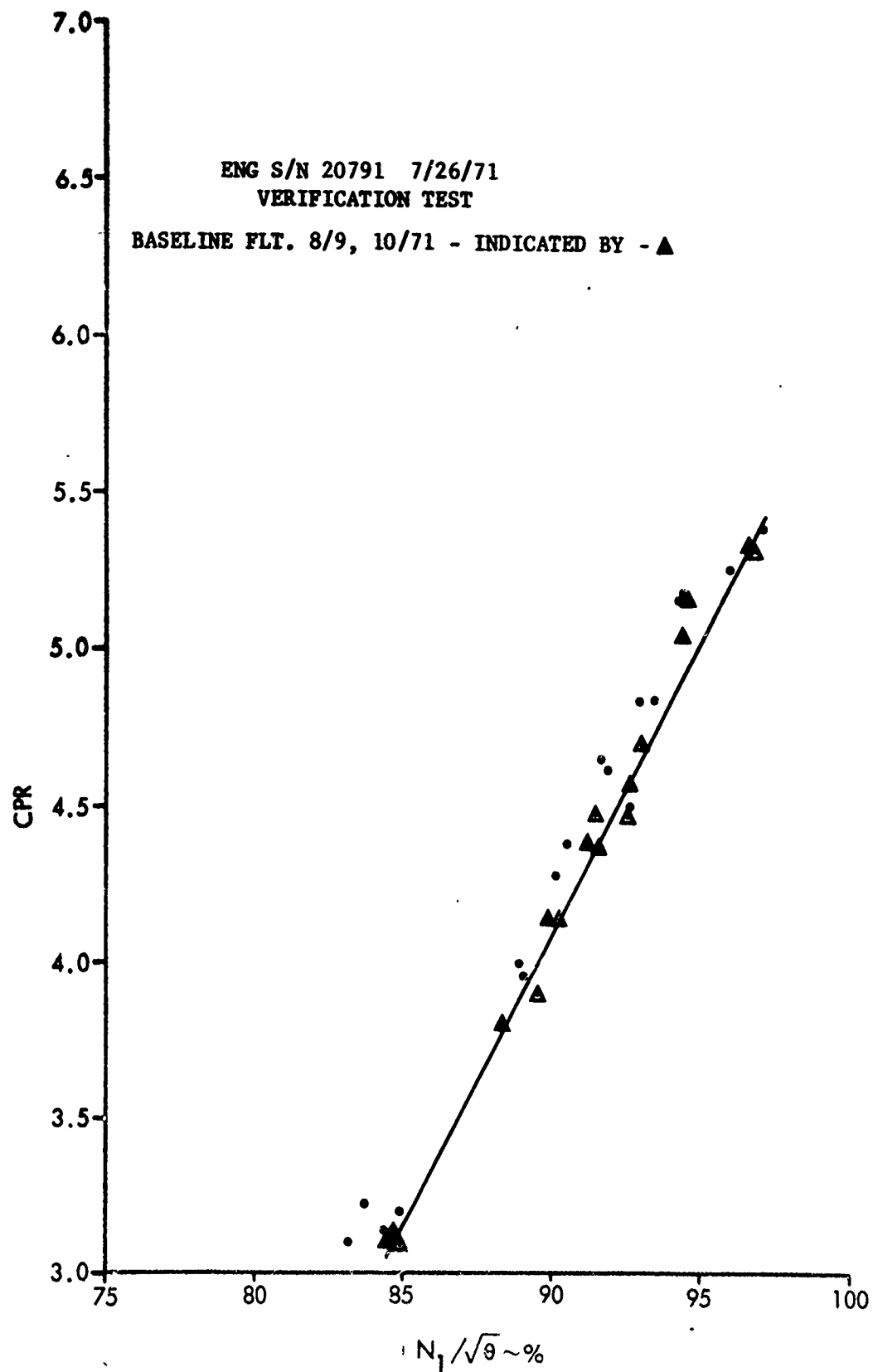


FIGURE 7-147 COMPRESSOR PRESSURE RATIO  
VS  
CORRECTED  $N_1$  SPEED

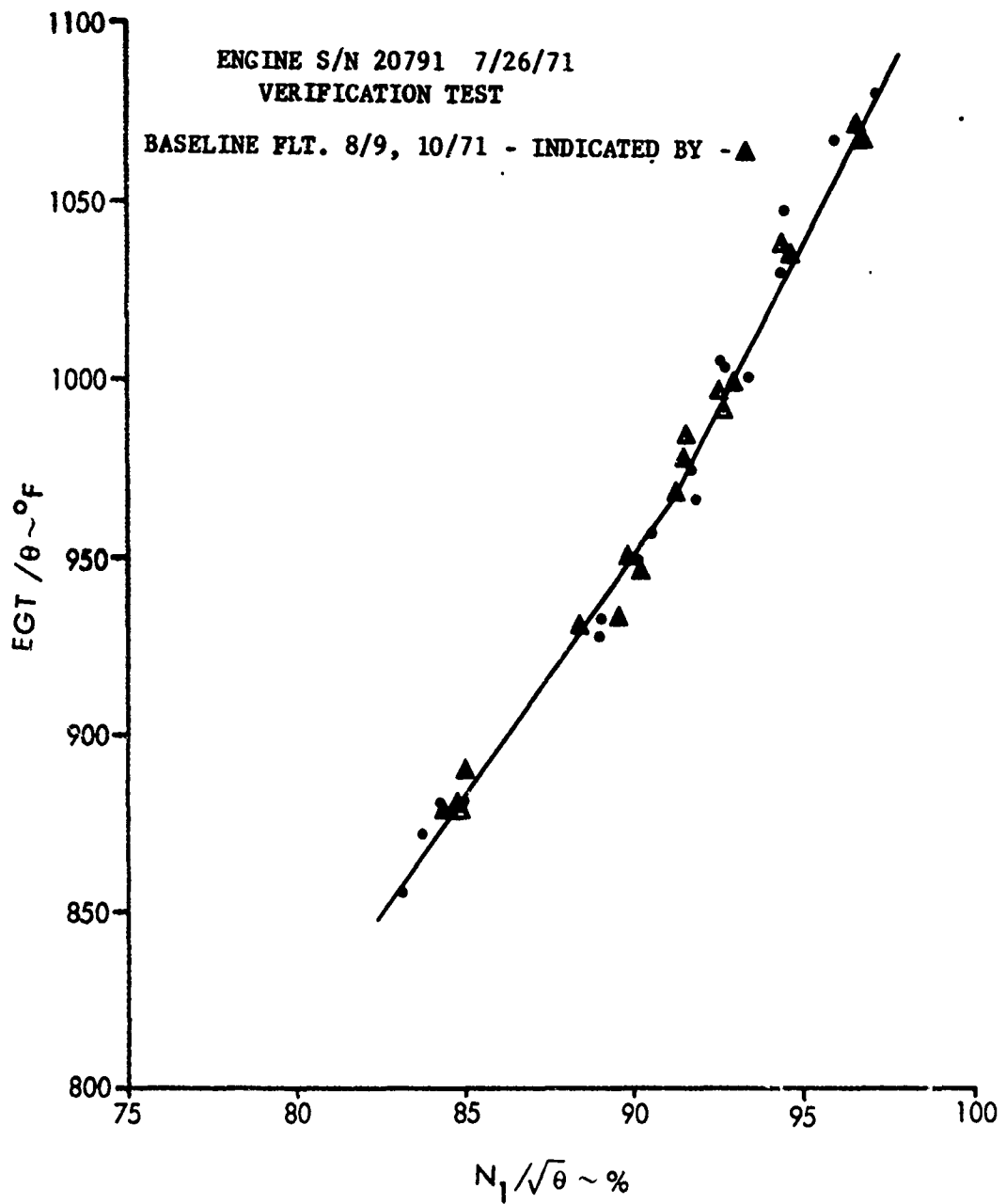


FIGURE 7-148 CORRECTED EXHAUST GAS TEMPERATURE  
VS  
CORRECTED  $N_1$  SPEED

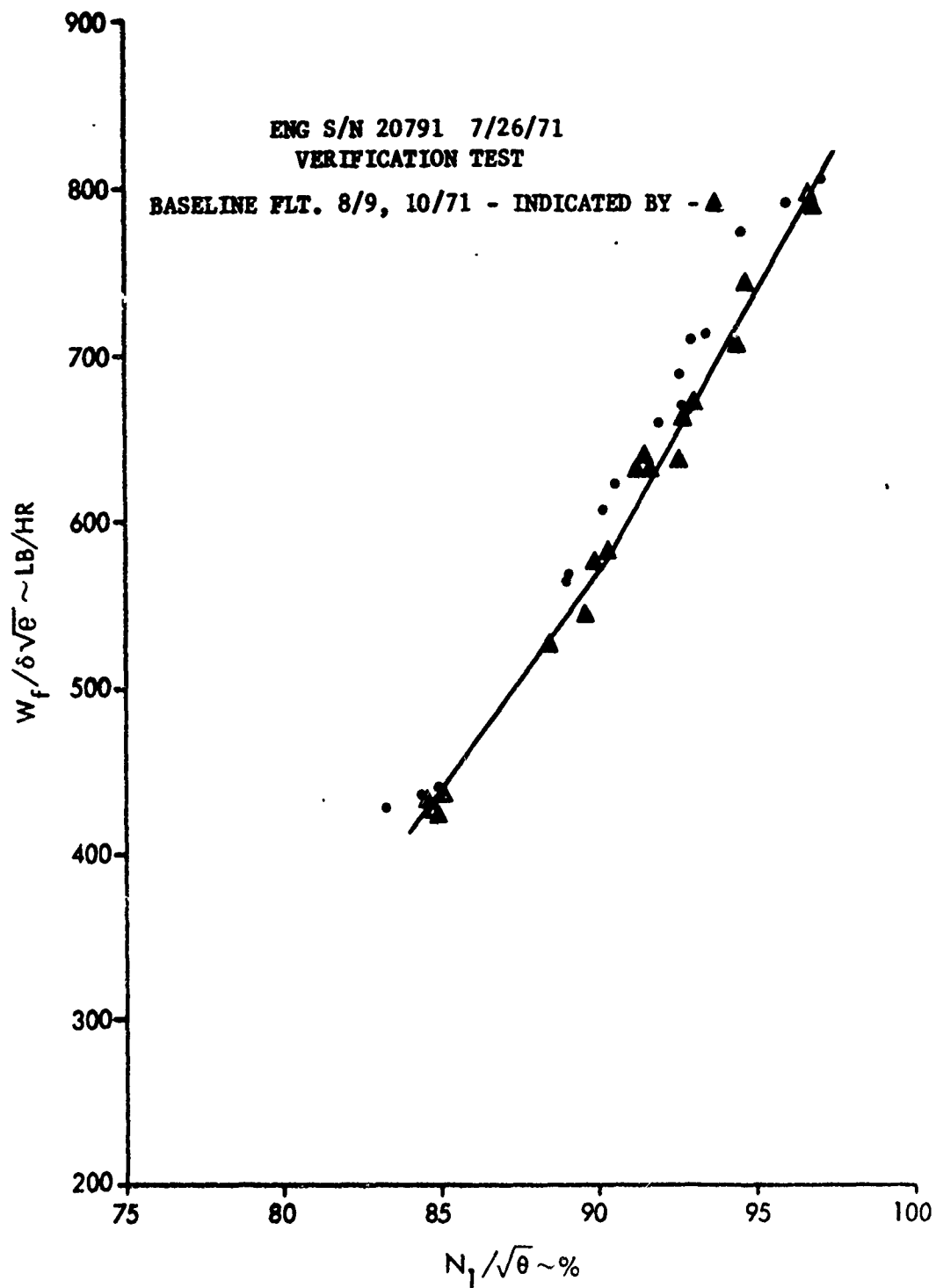
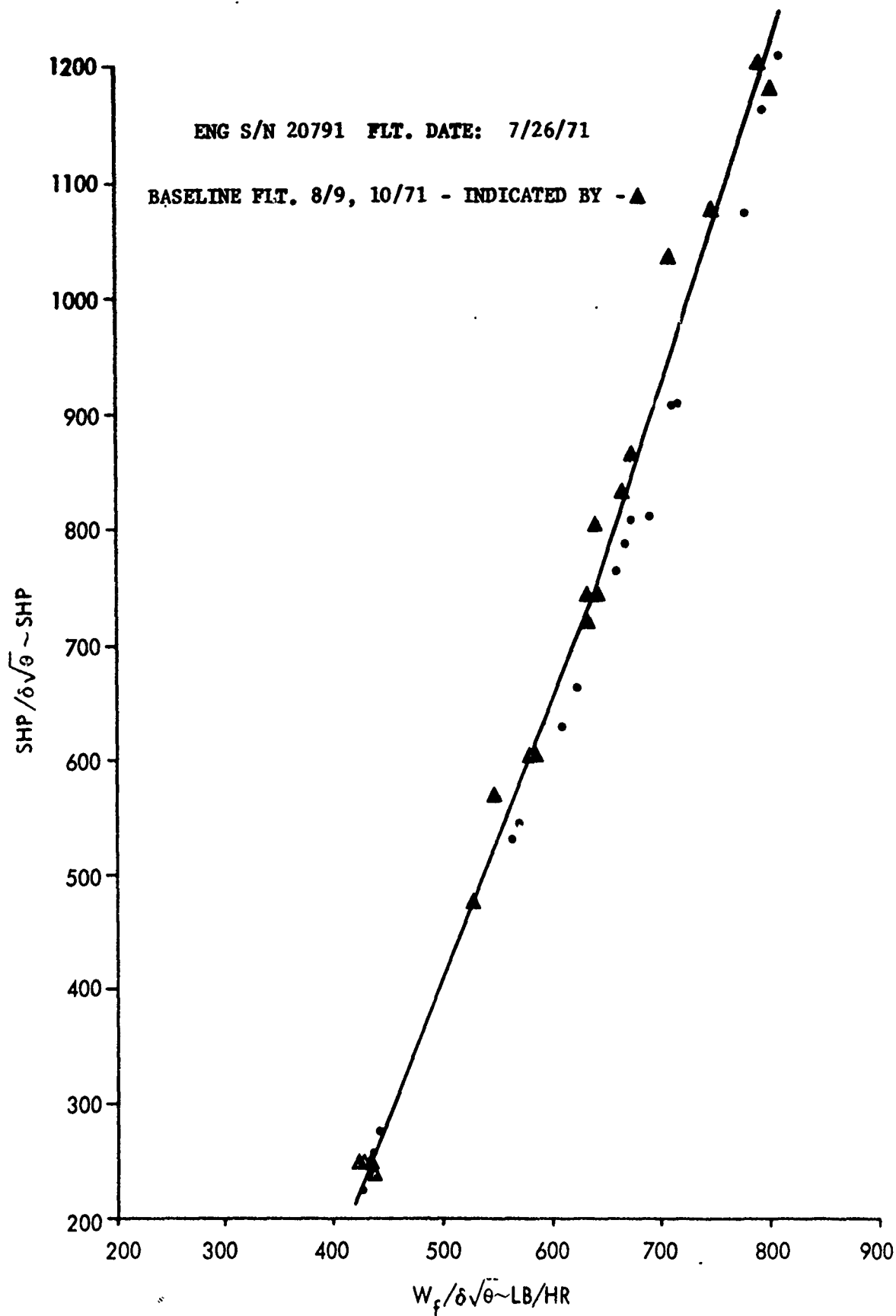


FIGURE 7-149 CORRECTED FUEL FLOW  
VS  
CORRECTED  $N_1$  SPEED



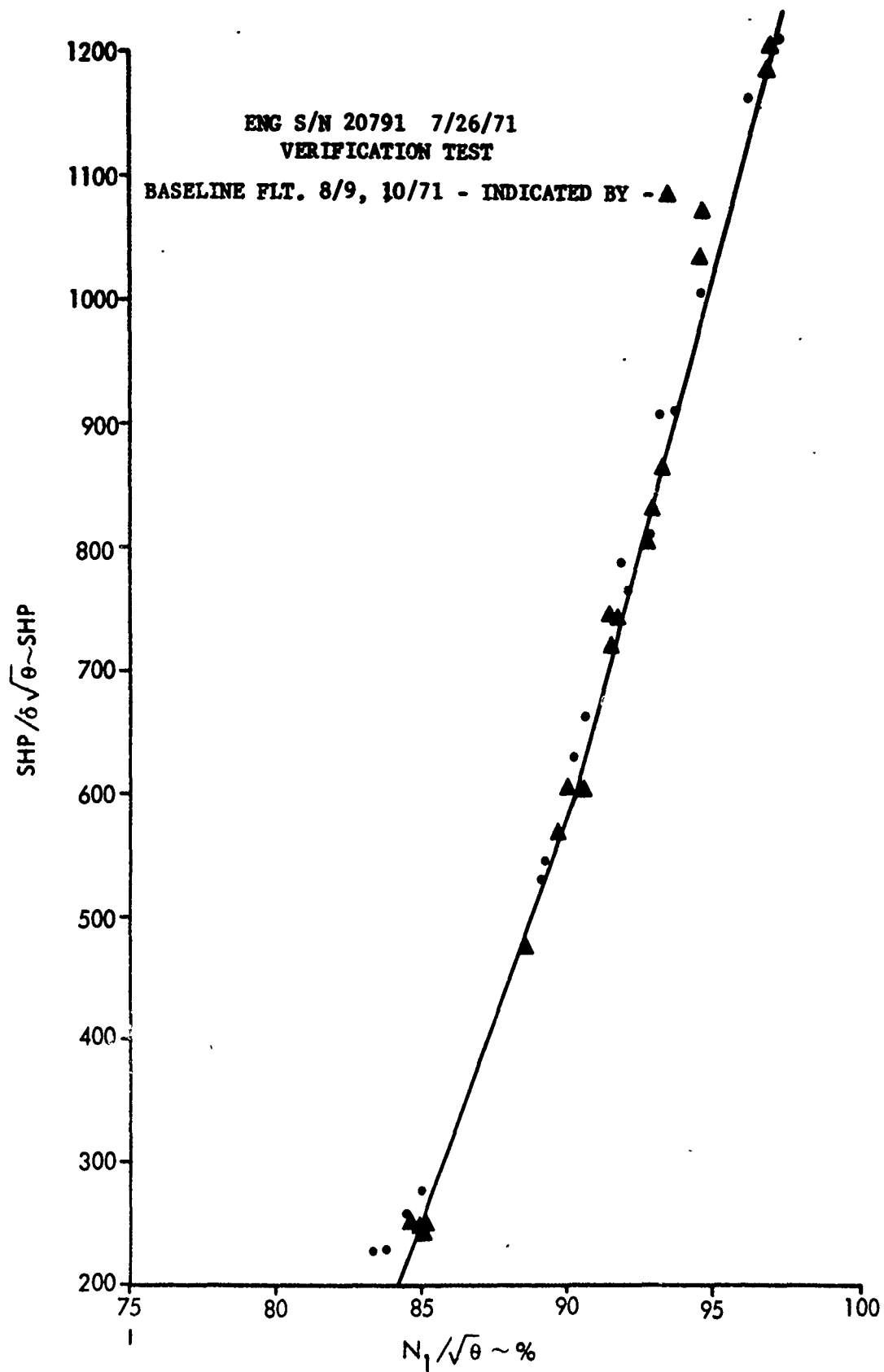


FIGURE 7-151 CORRECTED SHAFT HORSEPOWER  
 VS  
 CORRECTED  $N_1$  SPEED

Performance of the engine is shown in Figures 7-147 through 7-151. There is little difference between the verification and baseline performance. However, as stated previously, excessive vibration was noted on both tests. Since this engine was supposed to be "no defect" and should not have been disassembled between tests, the status of this component was questioned and a disassembly and inspection requested. Disassembly revealed evidence of a minor F.O.D. and an out of balance power turbine.

#### 7.9.5 COMPONENT SET NO. 4 (VERIFICATION CONDITION 4)

Set number 4 of verification components were installed in aircraft 67-17448 flown on 22 and 23 of July, 1971. Results of the verification test are as follows:

- Engine - MRS outputs indicate higher fuel flow rate than observed on previous baseline engines. Vibration is excessive. The engine should be removed and replaced.
- 42° Gearbox - Vibration levels are excessive, indicating a discrepant condition. The gearbox should be removed and replaced.
- 90° Gearbox - This component is operating within limits.
- Transmission - Vibration levels are normal.

Subsequent baseline of this set of components was installed in aircraft 67-17448 and flown on August 17, 1971. Results of the baseline tests are as follows:

- Engine - Fuel flow is high. Review of the data and results of previous tests indicate a broader baseline than previously experienced exists. Levels of detection should be adjusted. A vibration output from MRS was substantiated by analysis. However, levels were not as high as observed during verification flights. The verification diagnosis should be revised to indicate gas flow performance is good. However, vibration during verification is still considered excessive. The engine should be replaced.
- 42° Gearbox - An MRS output occurred during test. Review of the data verified the fact that the vibration levels were sufficient to cause an output. Data in this case, as in previous

verification baselines, indicates a consistency which in turn indicates a much wider baseline than provided by the one baseline component used to establish the detection criteria.

90° Gearbox - Vibration criteria indicates that the gearbox is operating within normal limits.

Transmission - Vibration levels indicate that the transmission is within acceptable limits.

Readjusted criteria used on the 42° gearbox data indicates the gearbox was good during both the verification and baseline tests (see Section 7.9.8). As in the case of the previous criteria, the input ball bearing used as the 42° gearbox implant did not cause significant vibration levels to occur.

Gas flow analysis of the engine is shown in Figures 7-154 through 7-158. Comparison of verification and baseline tests show a consistency of performance. Comparison of the fuel flow curves with those obtained during discrepant flight tests show a somewhat higher flow rate.

#### 7.9.6 COMPONENT SET NO. 5 (VERIFICATION CONDITION)

Set number 5 of verification components were installed in aircraft 66-17138 and flown on August 2, 1971. Results of the verification test are as follows:

Engine - Vibration levels indicate a marginal condition. Analysis experience indicates that a turbine, #3 or #4 bearing, or nozzles are degrading. The status of the engine should be monitored for continued indications of excessive vibration.

42° Gearbox - Vibration levels of the gearbox were excessive. The gearbox contains a discrepant and should be removed and replaced.

90° Gearbox - This component is degraded.

Transmission - Vibration levels are within normal operating limits.

Baseline of this set of components was flown on aircraft 67-17448 on August 27, 1971. Results of the baseline test are as follows:

Engine - Gas flow performance was good, but vibration levels are higher than those experienced during verification tests. The engine is apparently defective. Verification diagnosis does not require revision.

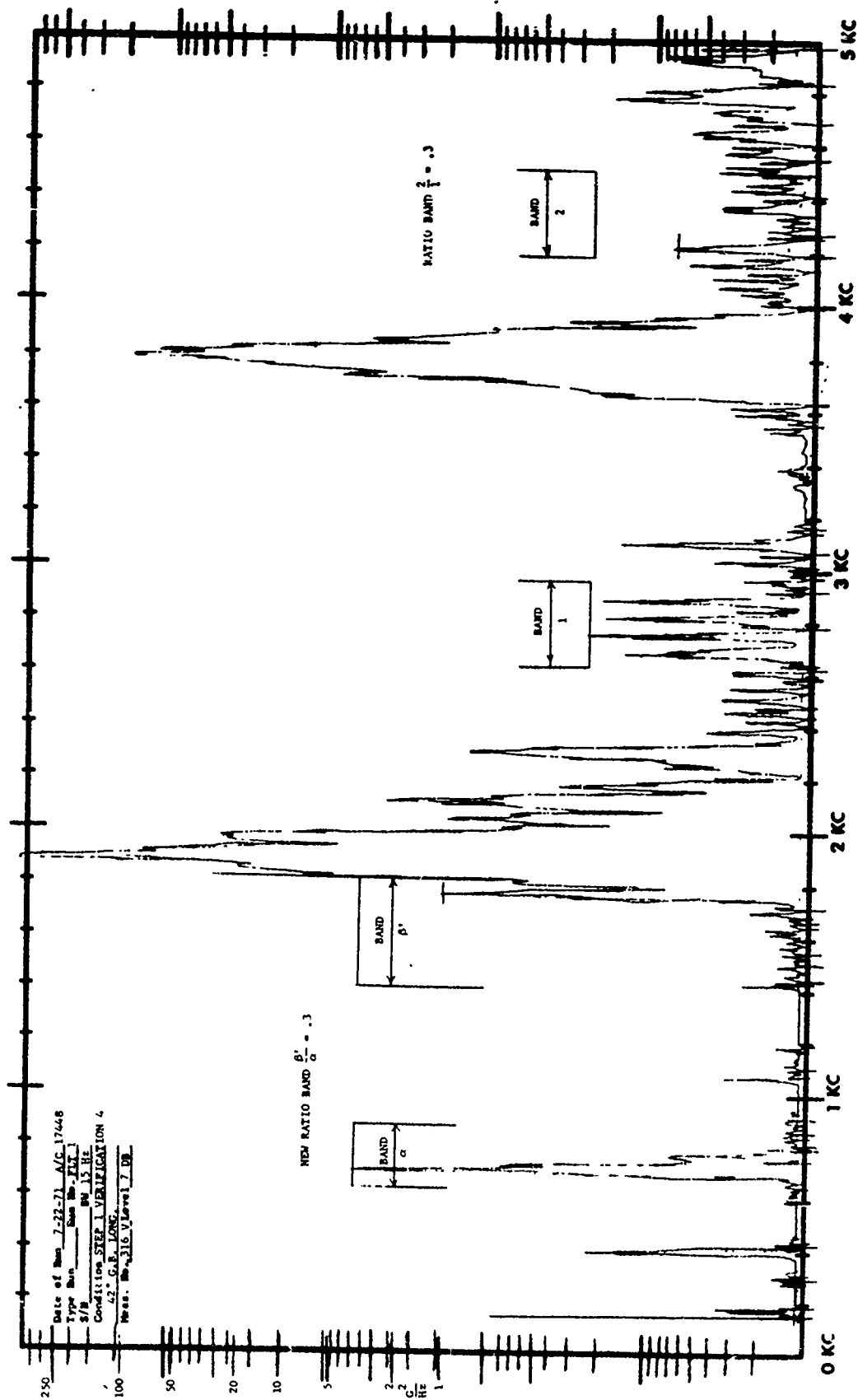


FIGURE 7-152 42° GEARBOX LONGITUDINAL, 7/22/71  
 A/C 17448, STEP 1, VERIFICATION 4

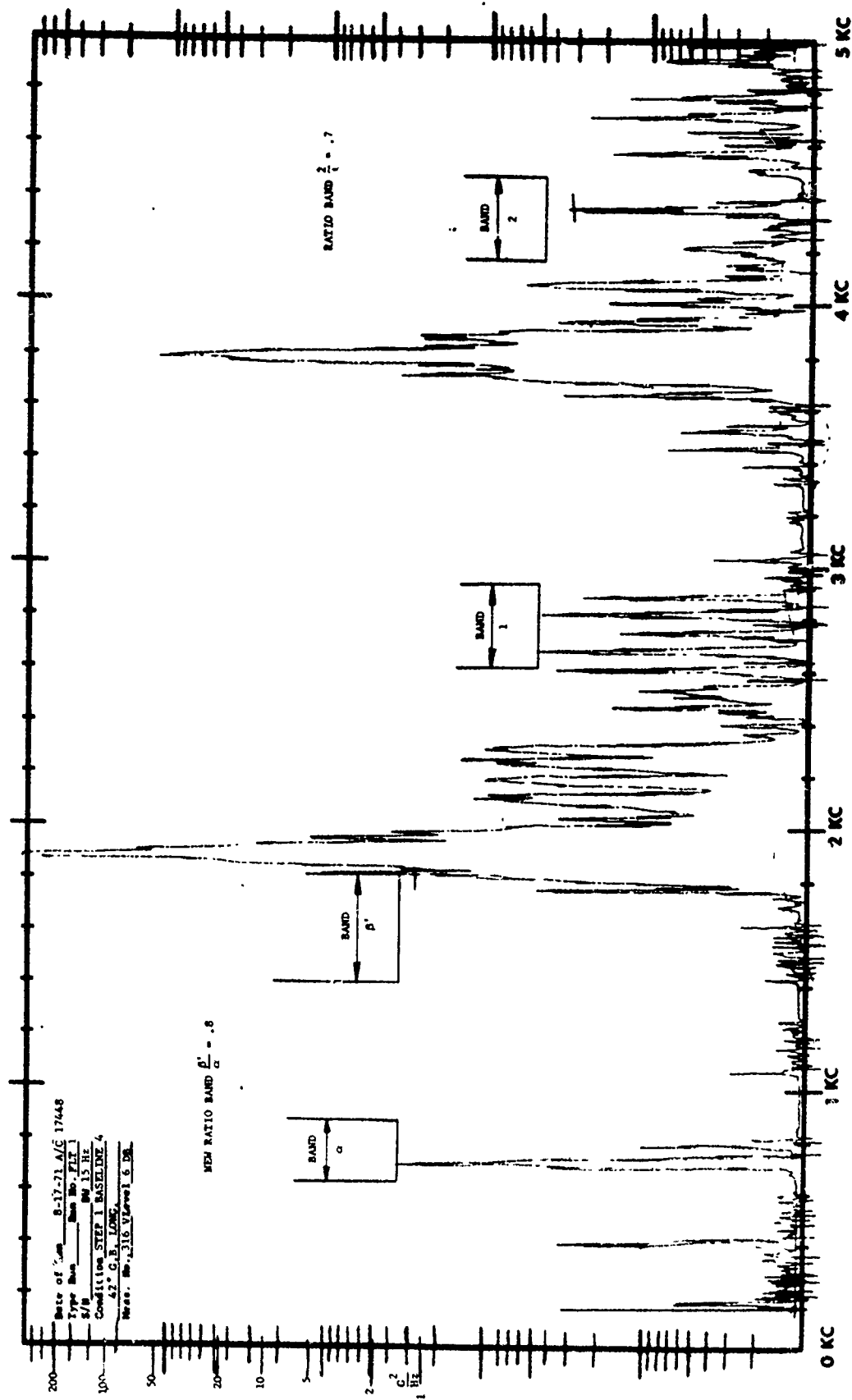


FIGURE 7-153 42° GEARBOX LONGITUDINAL, 8/17/71  
A/C 17448, STEP 1, BASELINE 4

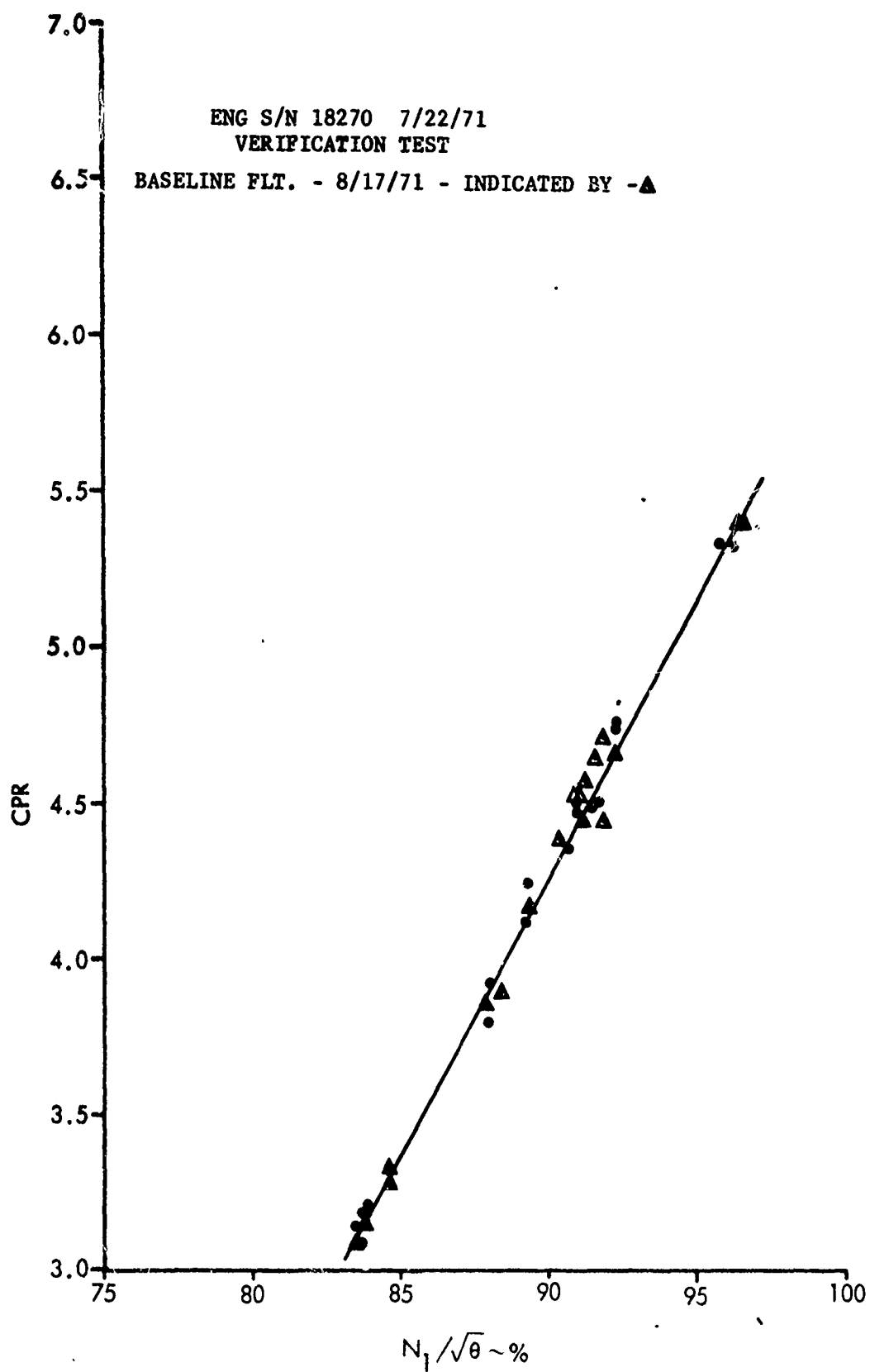


FIGURE 7-154 COMPRESSOR PRESSURE RATIO  
VS  
CORRECTED  $N_1$  SPEED

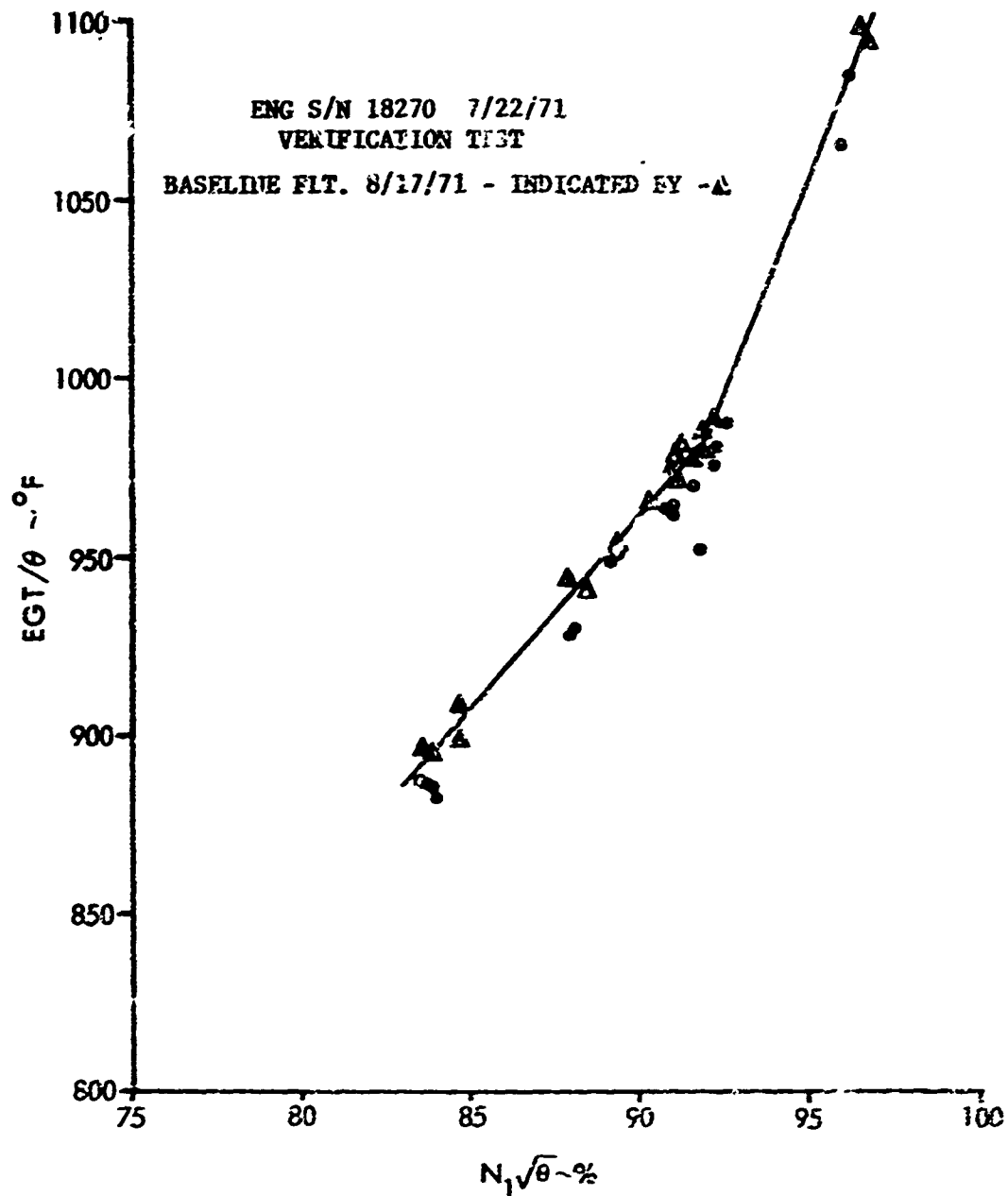


FIGURE 7-155 CORRECTED EXHAUST GAS TEMPERATURE  
VS  
CORRECTED  $N_1$  SPEED

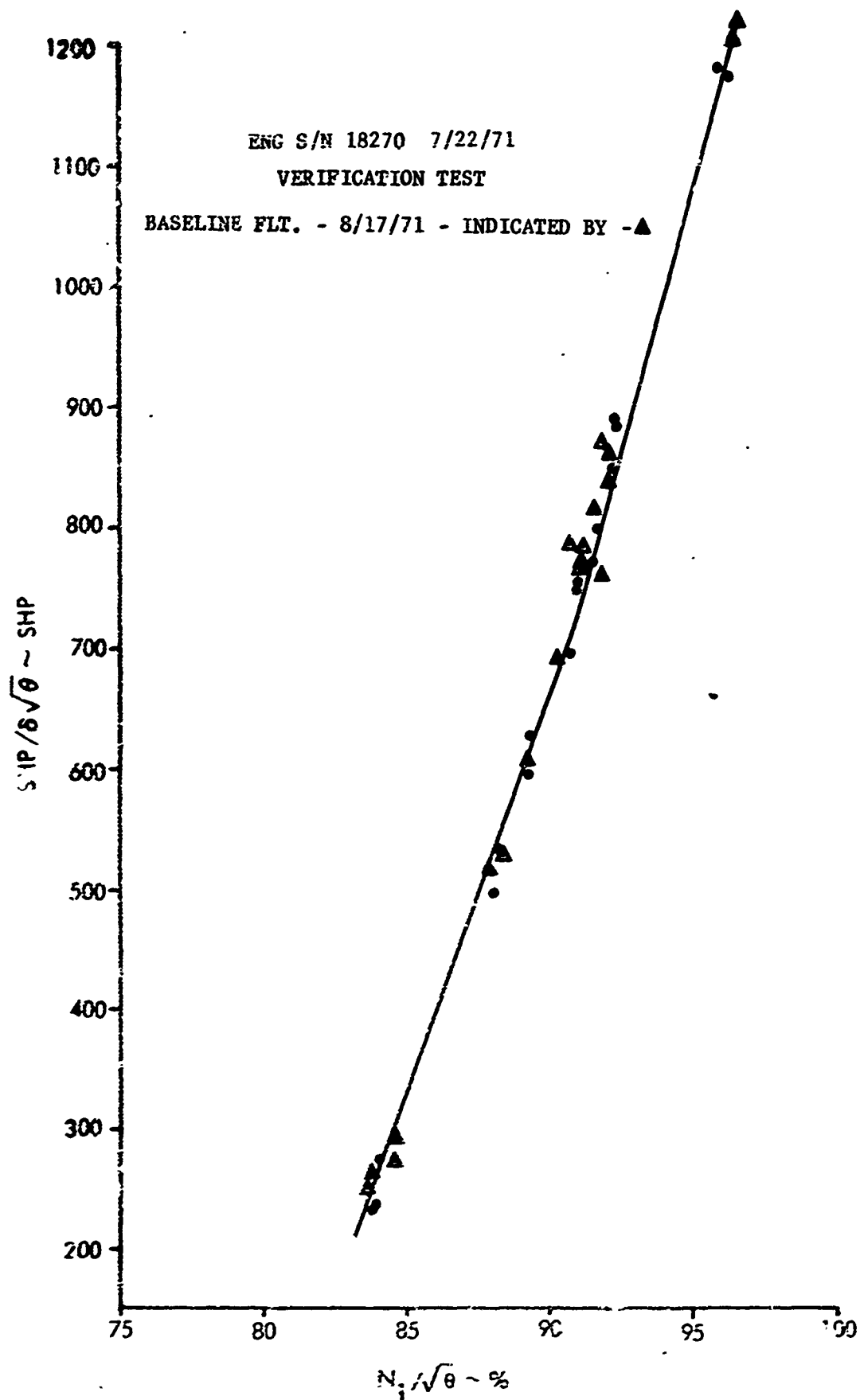


FIGURE 7-156 CORRECTED SHAFT HORSEPOWER  
VS  
CORRECTED  $N_1$  SPEED

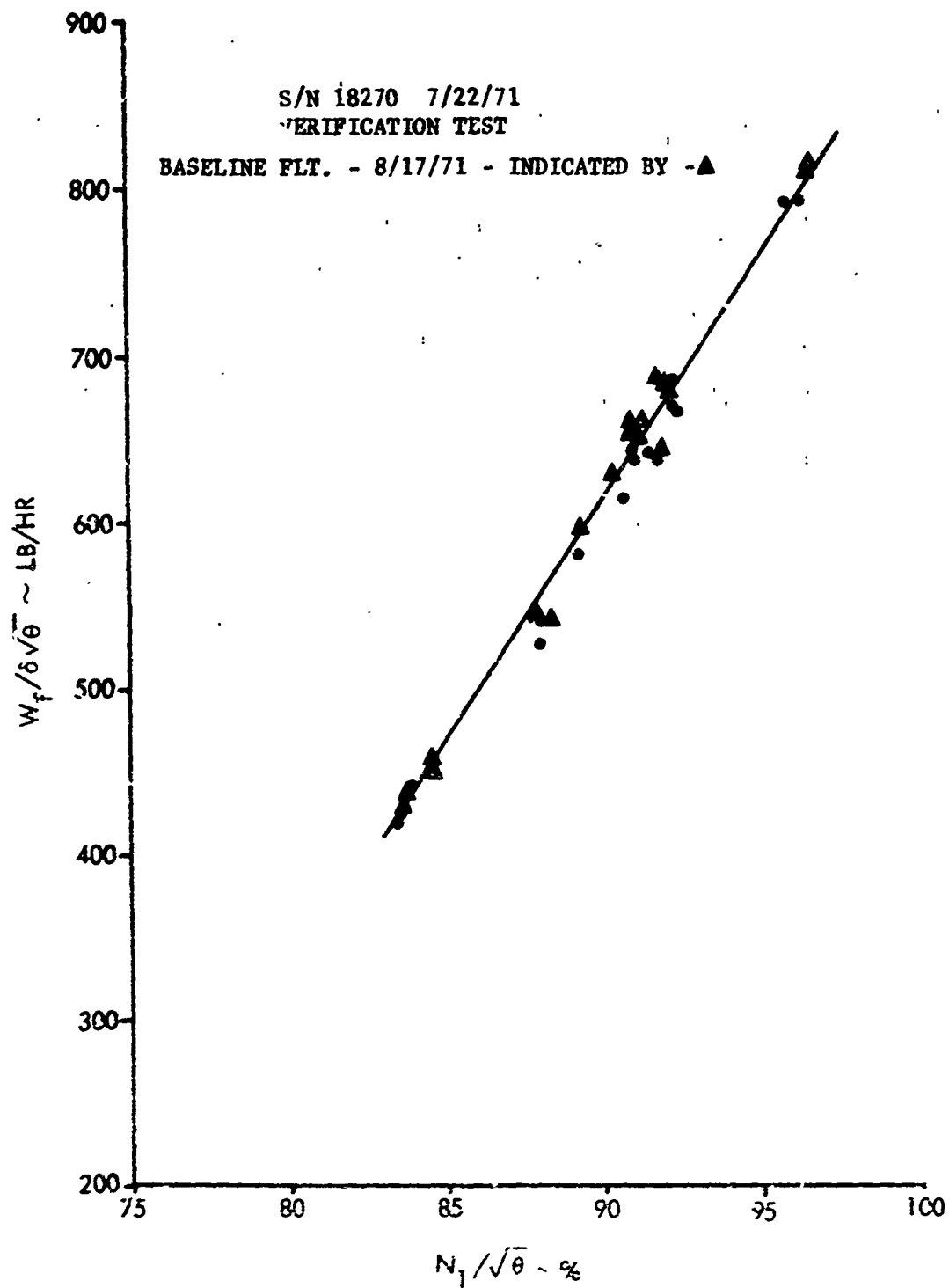


FIGURE 7-157 CORRECTED FUEL FLOW  
 VS  
 CORRECTED  $N_1$  SPEED

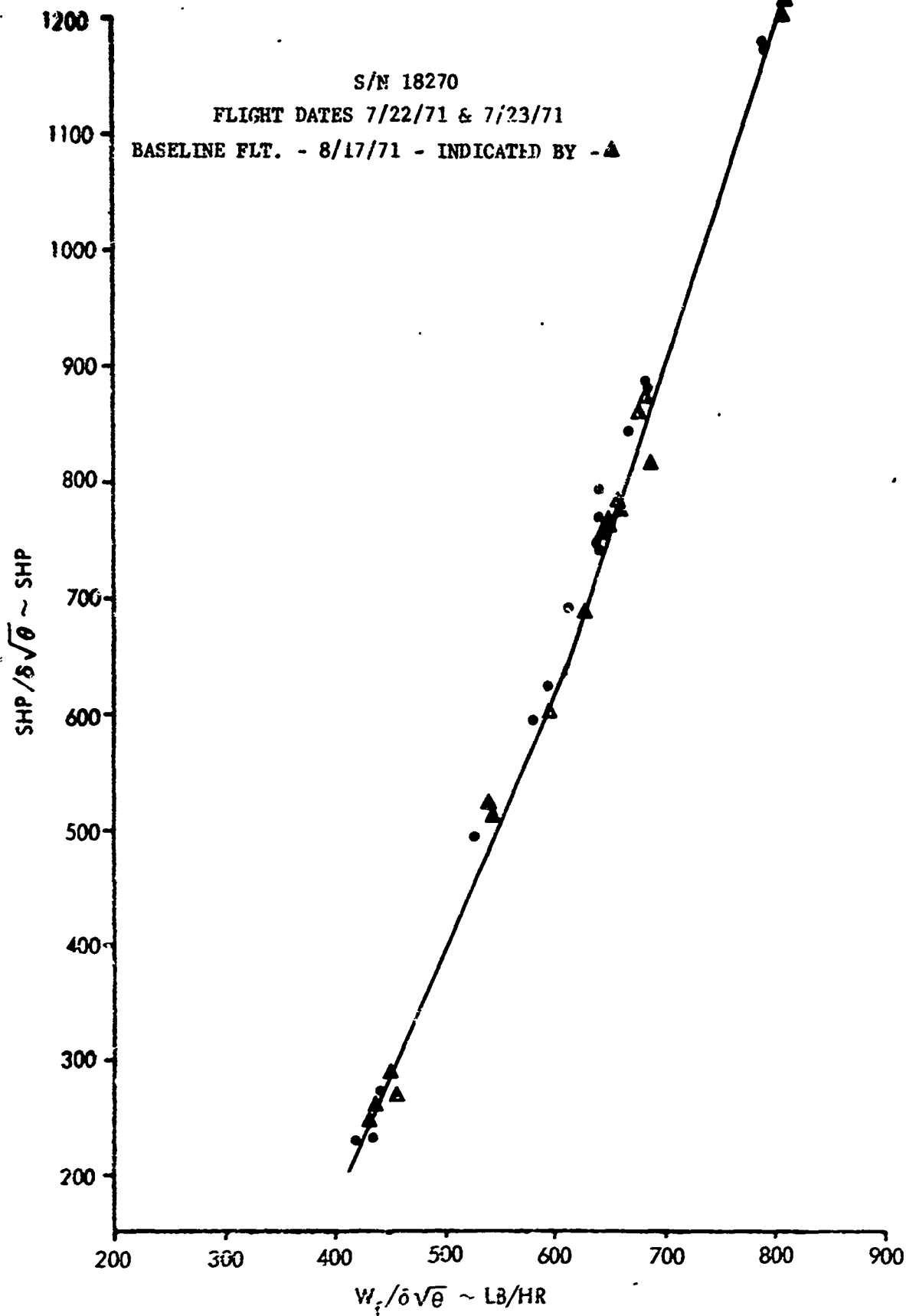


FIGURE 7-158 CORRECTED SHAFT HORSEPOWER  
VS  
CORRECTED FUEL FLOW

42° Gearbox - Vibration levels were excessive. No revision to verification diagnosis is required.

90° Gearbox - Normal operating limits have almost been exceeded for this component. It should be observed for continued degradation.

Transmission - This component is also operating marginally.

Using the readjusted criteria for the 42° gearbox, the vibration levels indicated the gearbox was good in both verification and baseline.

Correlation of engine gas flow performance during verification and baseline flights indicates only one difference (see Figures 7-151 through 7-165). The verification engine produced consistently lower exhaust gas temperature. The lower EGT values were confirmed from the calculator data.

The verification vibration analysis procedure indicated definite  $N_1$  nozzle deterioration (high B/A). Analysis of the baseline flight plainly indicated that the nozzle problem had been corrected but vibration was still excessive, especially during the climb mode. This engine was subsequently torn down and inspected. As a result of the action, it was determined that the engine drive shaft adapter plate was severely warped. Figures 7-166 and 7-167 show an expanded PSD (500 Hz Full Scale) of this engine during verification and during baseline. Note the significant increase in energy at the 106 Hz during baseline. The warped coupler is responsible for this increase. Warped couplers were not included within the baseline of faulty components to be detected; however, the MRS hardware mechanization indicated a vibration problem. If this is a critical maintenance area, a new filter band can be mechanized in the VSA to fault isolate to this specific problem.

#### 7.9.7 COMPONENT SET NO. 6 (VERIFICATION CONDITION 6)

Set number 6 of verification components was installed in aircraft 67-17448 flown on July 30, 1971. Results of the verification test are as follows:

Engine - Engine performance is unquestionably not good. Health indicators identify the presence of a degraded compressor. Vibration levels are also excessive. The engine probably has a bad F.O.D. compressor and should be removed and replaced.

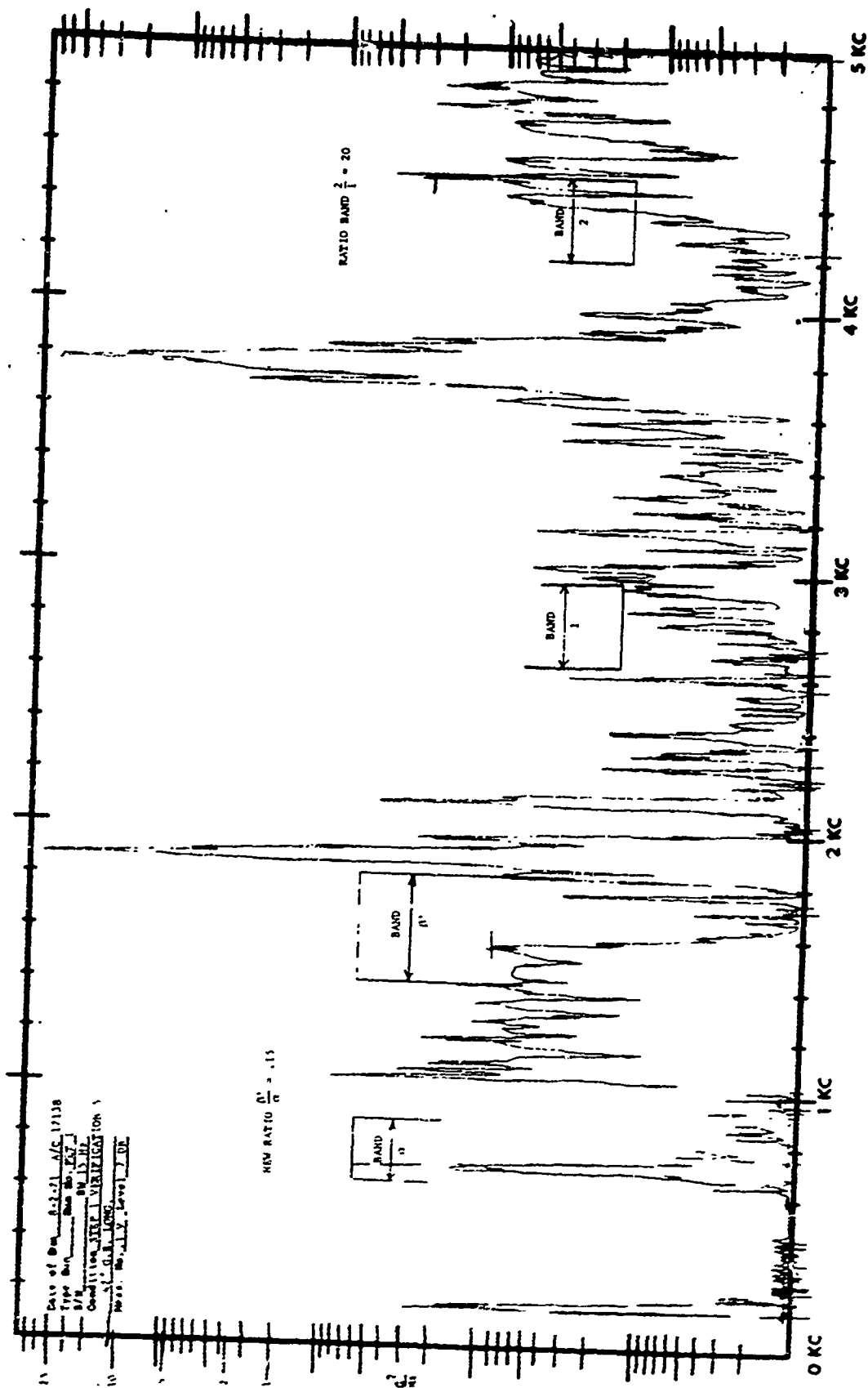


FIGURE 7-159 42° GEARBOX LONGITUDINAL, 8/2/71  
 A/C 17138, STEP 1, VERIFICATION 5

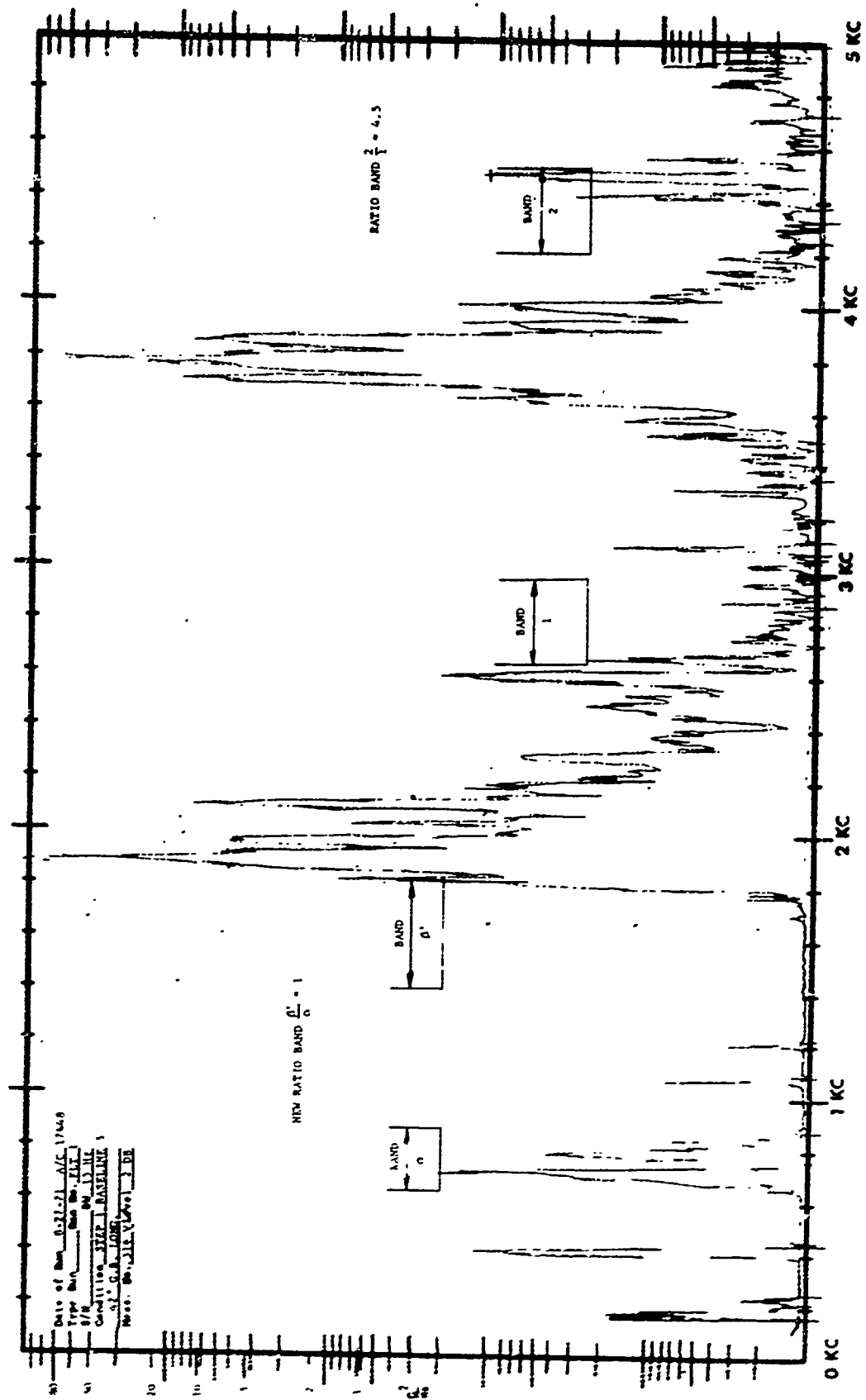


FIGURE 7-160 42° GEARBOX LONGITUDINAL, 8/27/71  
 A/C 17448, STEP 1, BASELINE 5

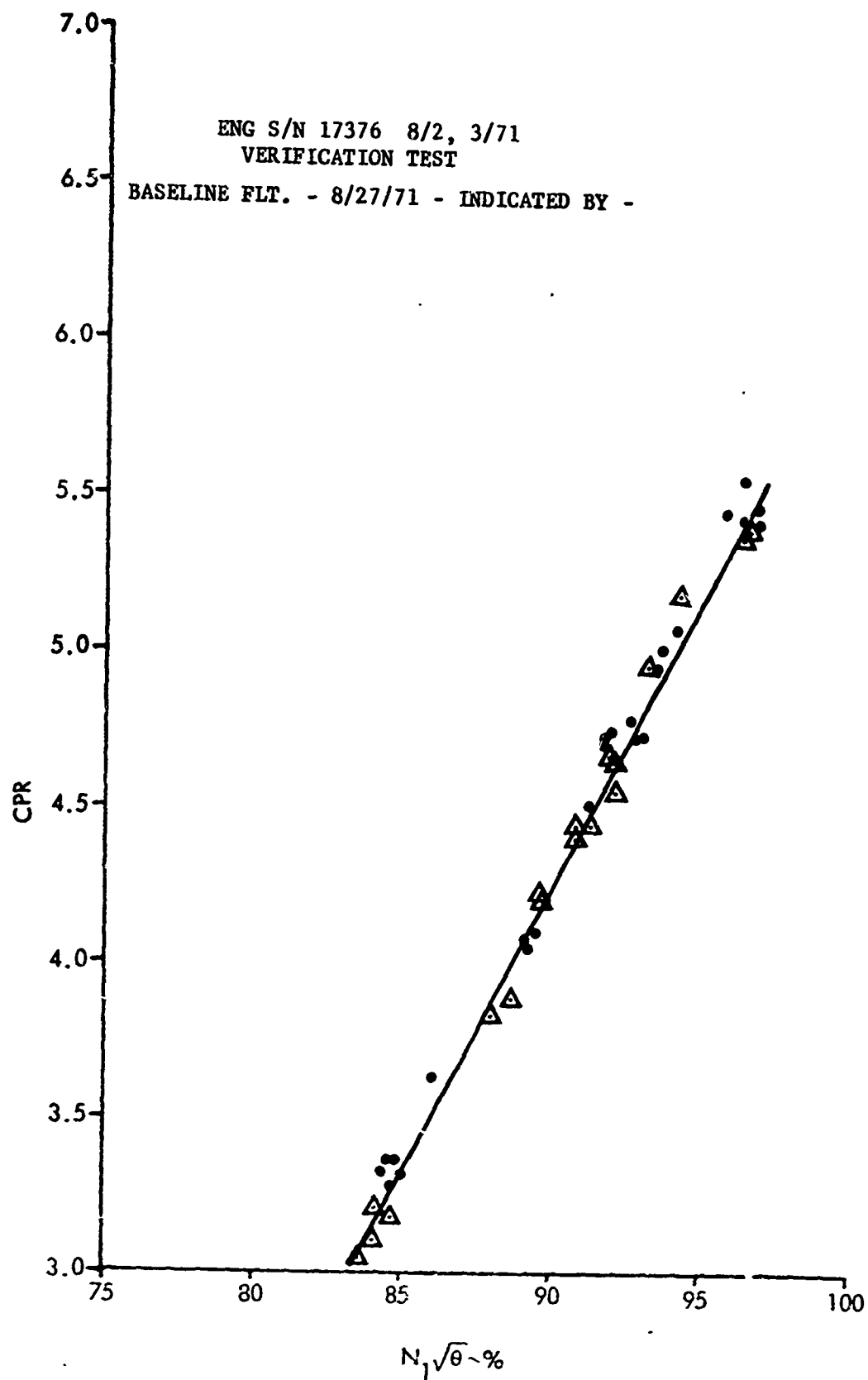


FIGURE 7-161 COMPRESSOR PRESSURE RATIO  
VS  
CORRECTED  $N_1$  SPEED



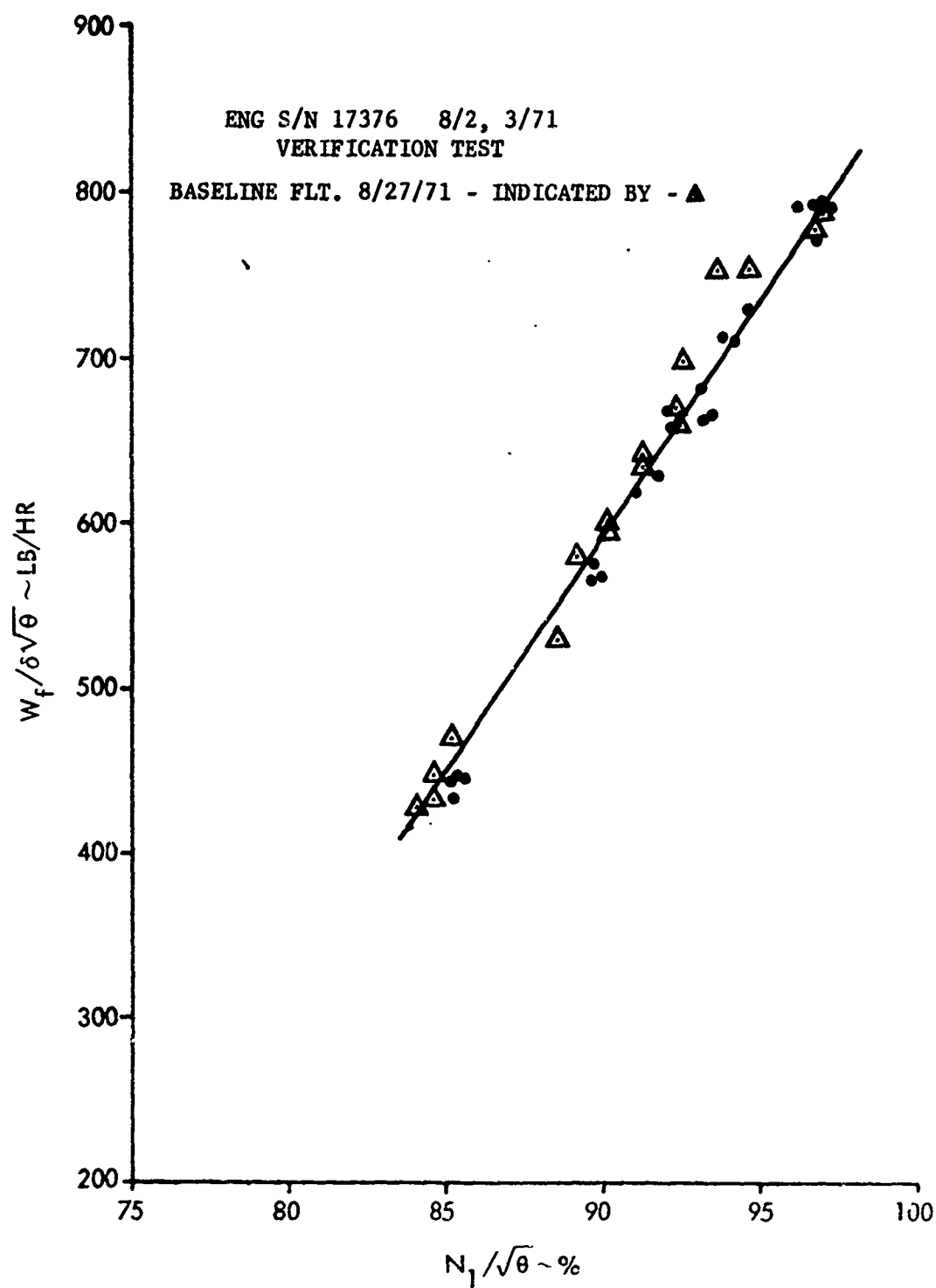


FIGURE 7-163 CORRECTED FUEL FLOW  
 VS  
 CORRECTED  $N_1$  SPEED

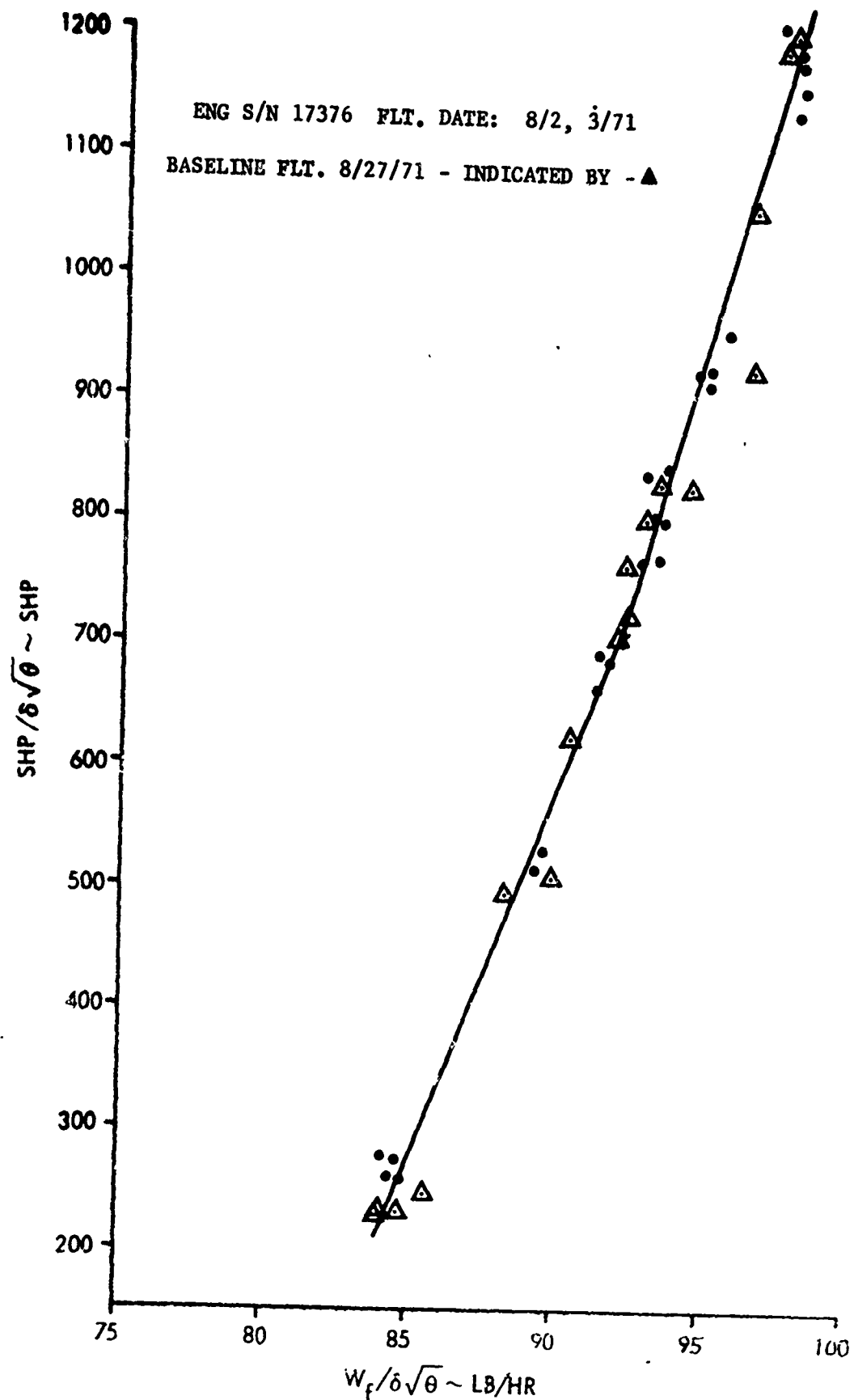


FIGURE 7-164 CORRECTED SHAFT HORSEPOWER  
VS  
CORRECTED FUEL FLOW

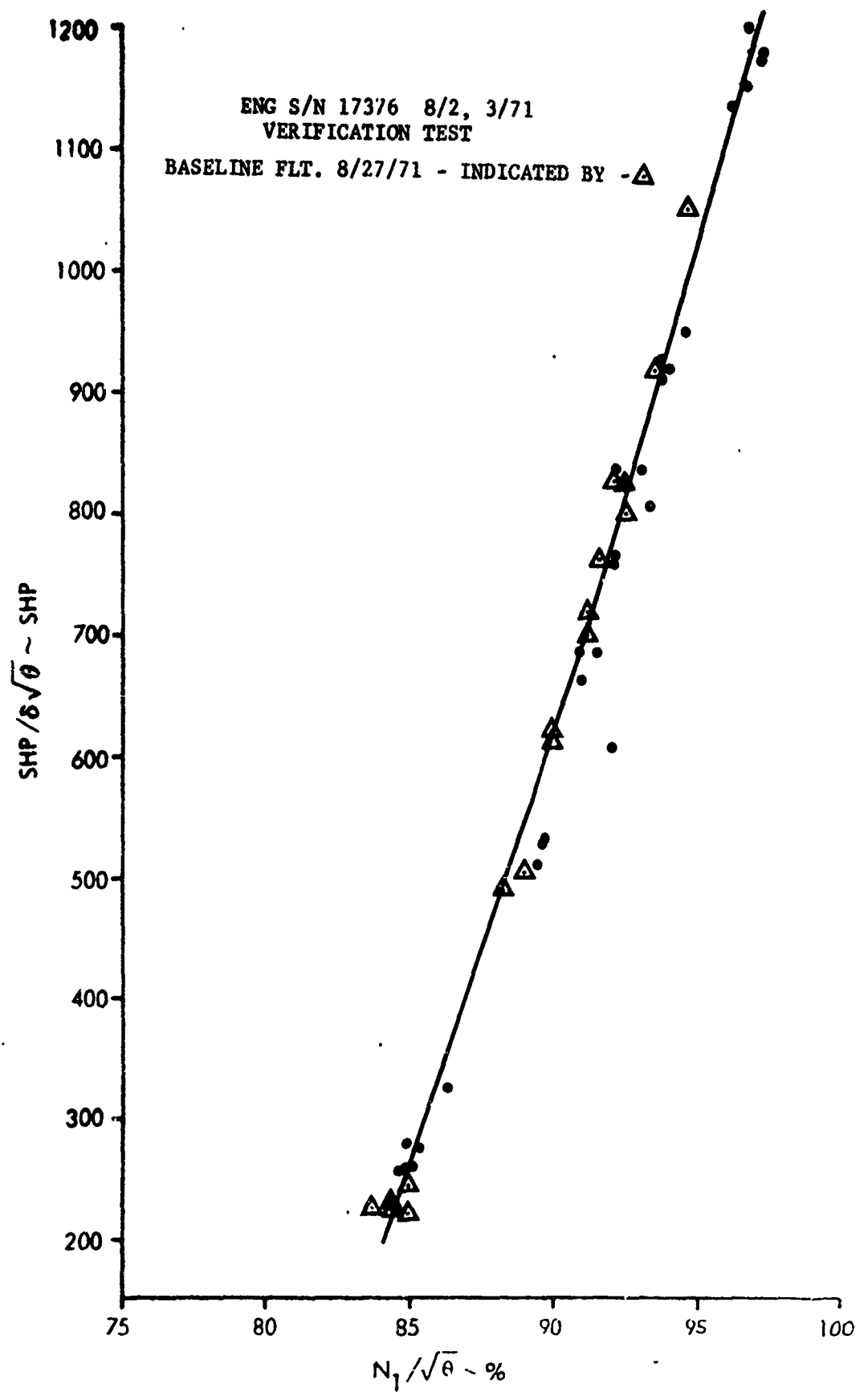


FIGURE 7-165 CORRECTED SHAFT HORSEPOWER  
VS  
CORRECTED  $N_1$  SPEED

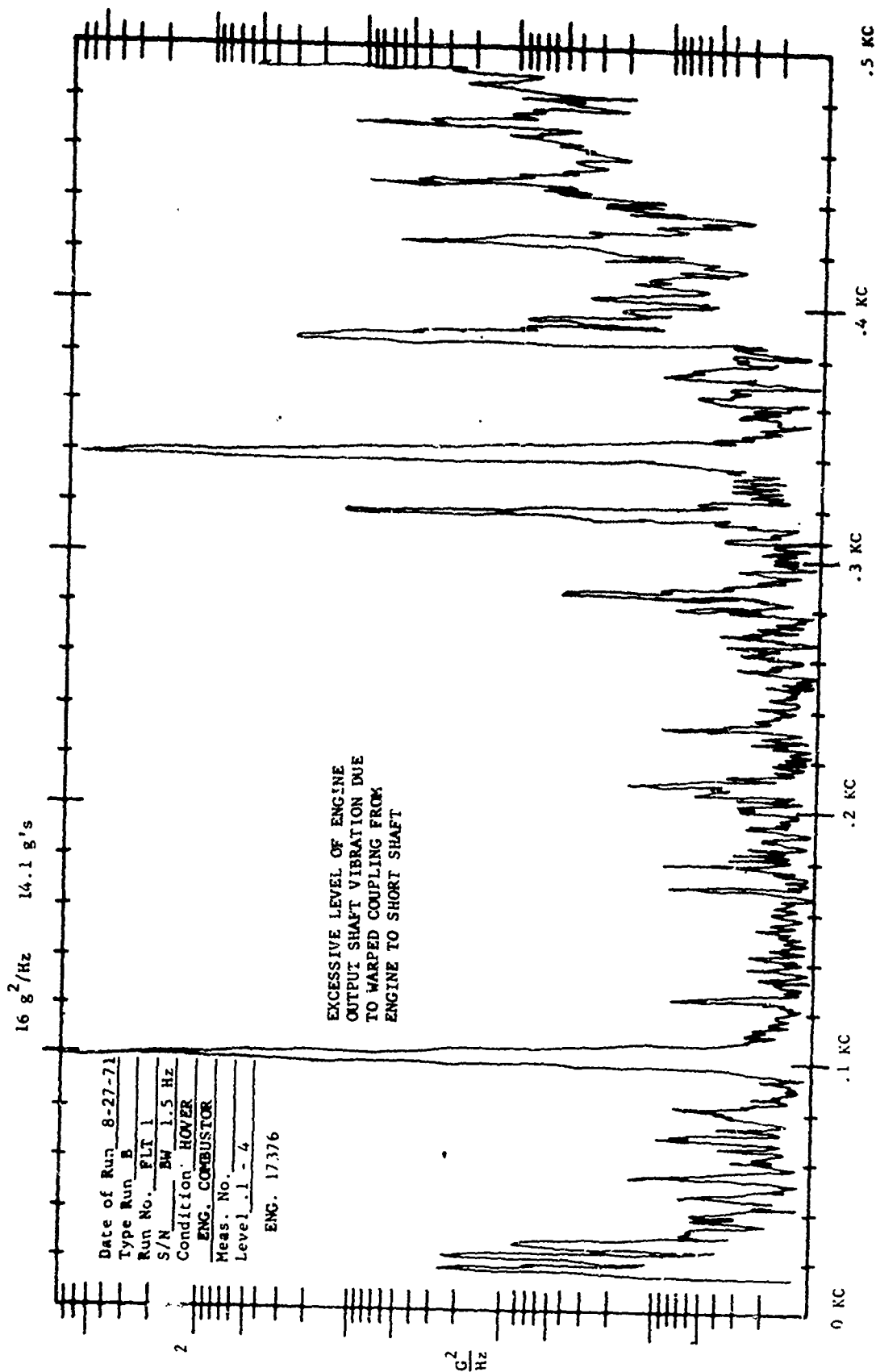


FIGURE 7-166 ENGINE VIBRATION WITH WARPED ADAPTER PLATE

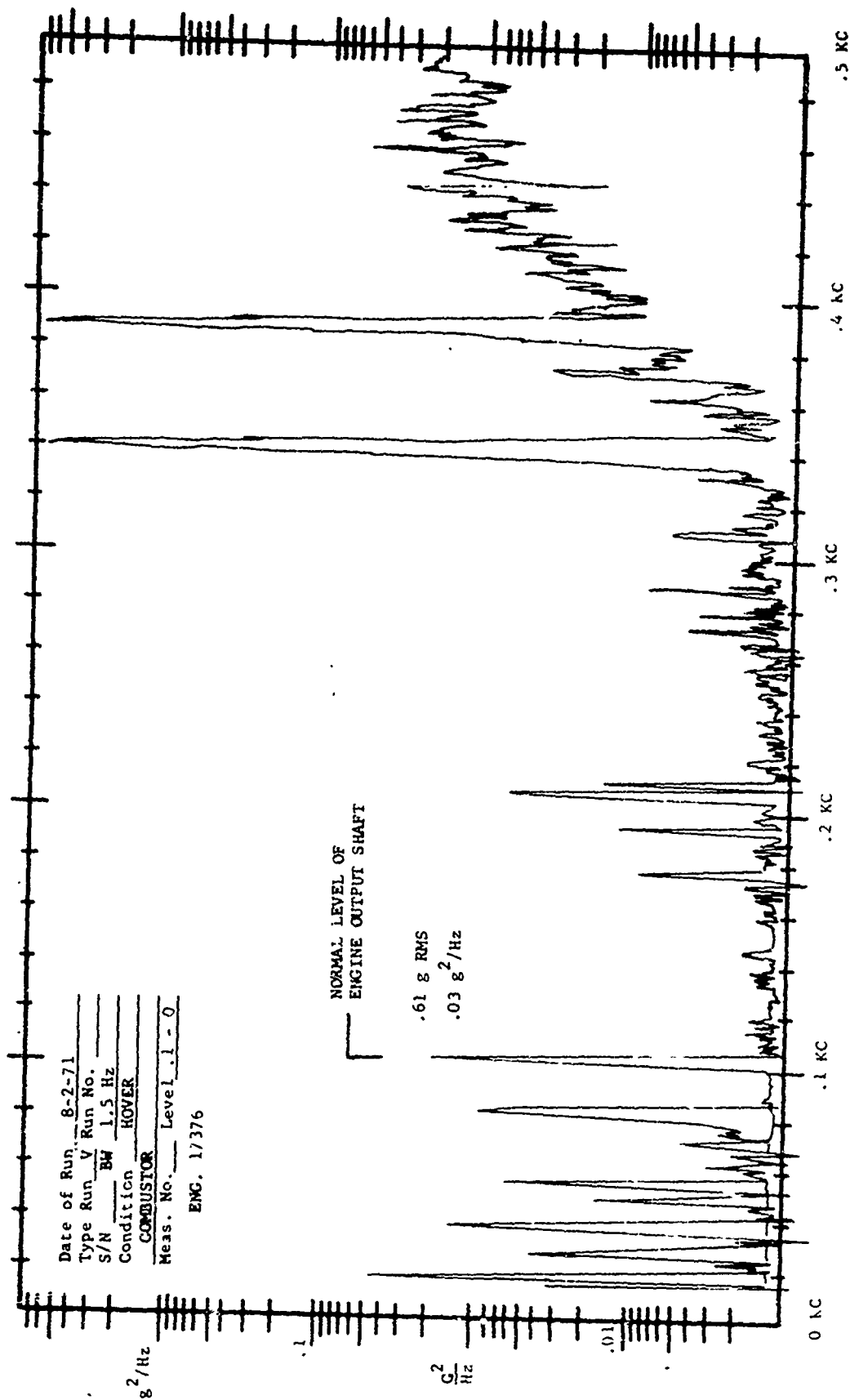


FIGURE 7-167 ENGINE VIBRATION WITH WARPED ADAPTER PLATE

42° Gearbox - No evidence of a discrepant condition exists. The gearbox is considered good.

90° Gearbox - This component is within normal vibration limits.

Transmission - Vibration levels indicate that the transmission is degraded.

The subsequent baseline of this set of components was flown in aircraft 67-17448 August 23, 1971. Results of the baseline test are as follows:

Engine - Engine performance is good. No change to verification diagnosis is required.

42° Gearbox - Evaluation of data indicates the gearbox is degraded. Verification diagnosis does not require change.

90° Gearbox - Vibration data indicates that the performance is acceptable.

Transmission - In spite of the fact that this is a baseline data gathering activity, the vibration information indicates that the transmission is degraded.

Readjusted criteria for the 42° gearbox indicated that the verification gearbox was bad and the baseline gearbox was good. This criteria is more fully explained in Volume II.

Figures 7-170 to 7-174 present the comparison of the verification and baseline engine performance data. The verification test engine produced a positive indication of a severe compressor problem. Low compressor pressure ratio, high exhaust gas temperature, and low shaft horsepower as a function of engine speed are the typical engine performance deficiencies associated with a degraded compressor engine. Supporting data was also observed from the calculator which indicated low KCPR and high KEGT values.

The vibration analysis criteria indicated a gross baseline engine vibration problem. Baseline for this engine is normal except for 1000' - 115 kts, where the threshold level is exceeded by almost 100 percent. This engine, although greatly improved over verification, still tends to vibrate above prescribed limits.

#### 7.9.8 VERIFICATION DATA SUMMARY

Due to the nature of the discrepant implants used during the verification test, significant diagnostic data was primarily vibrational. A summary of vibration data for each of the components tested is, therefore, presented in

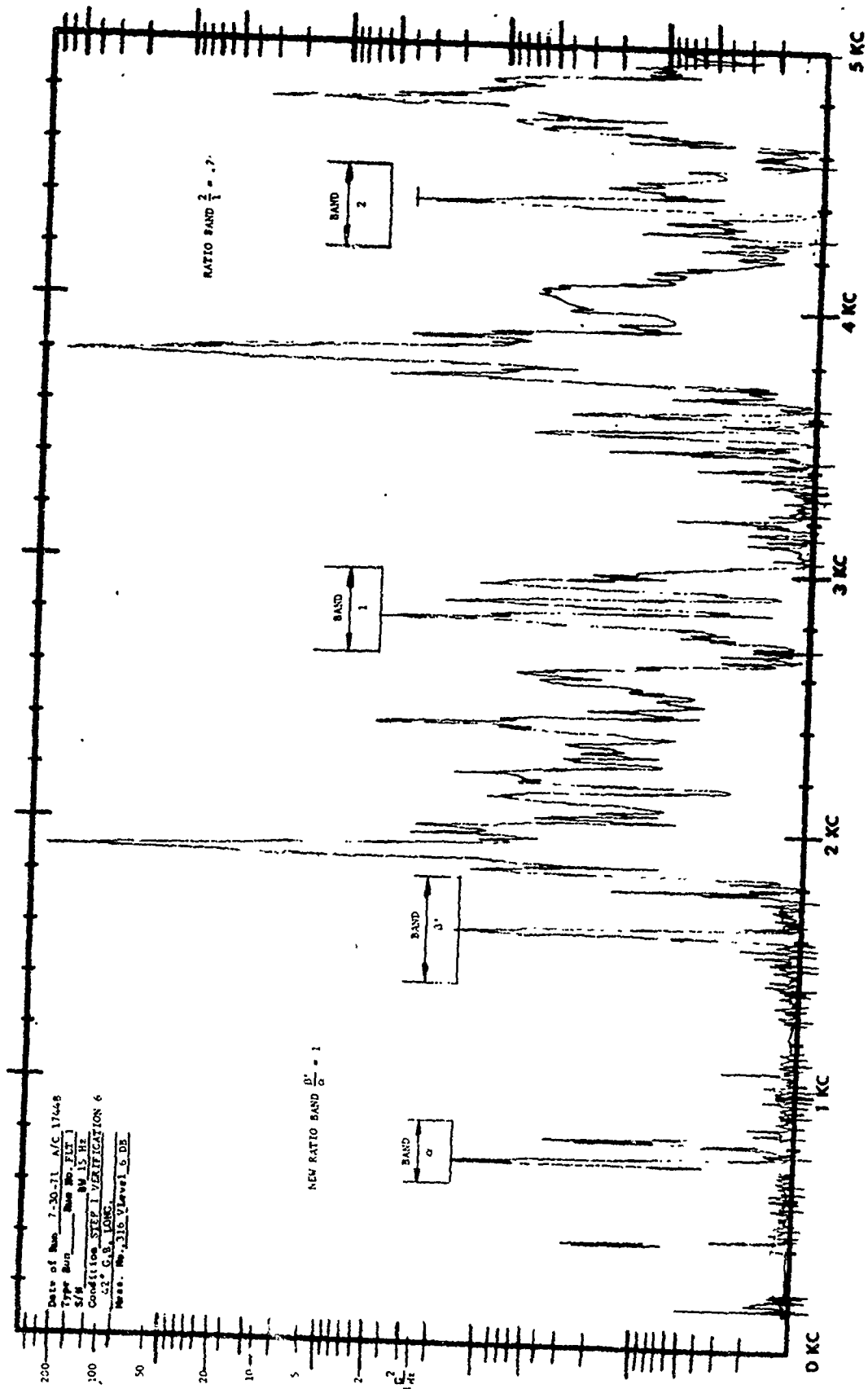


FIGURE 7-168 42° GEARBOX LONGITUDINAL, 7/30/71  
 A/C 17448, STEP 1, VERIFICATION 6

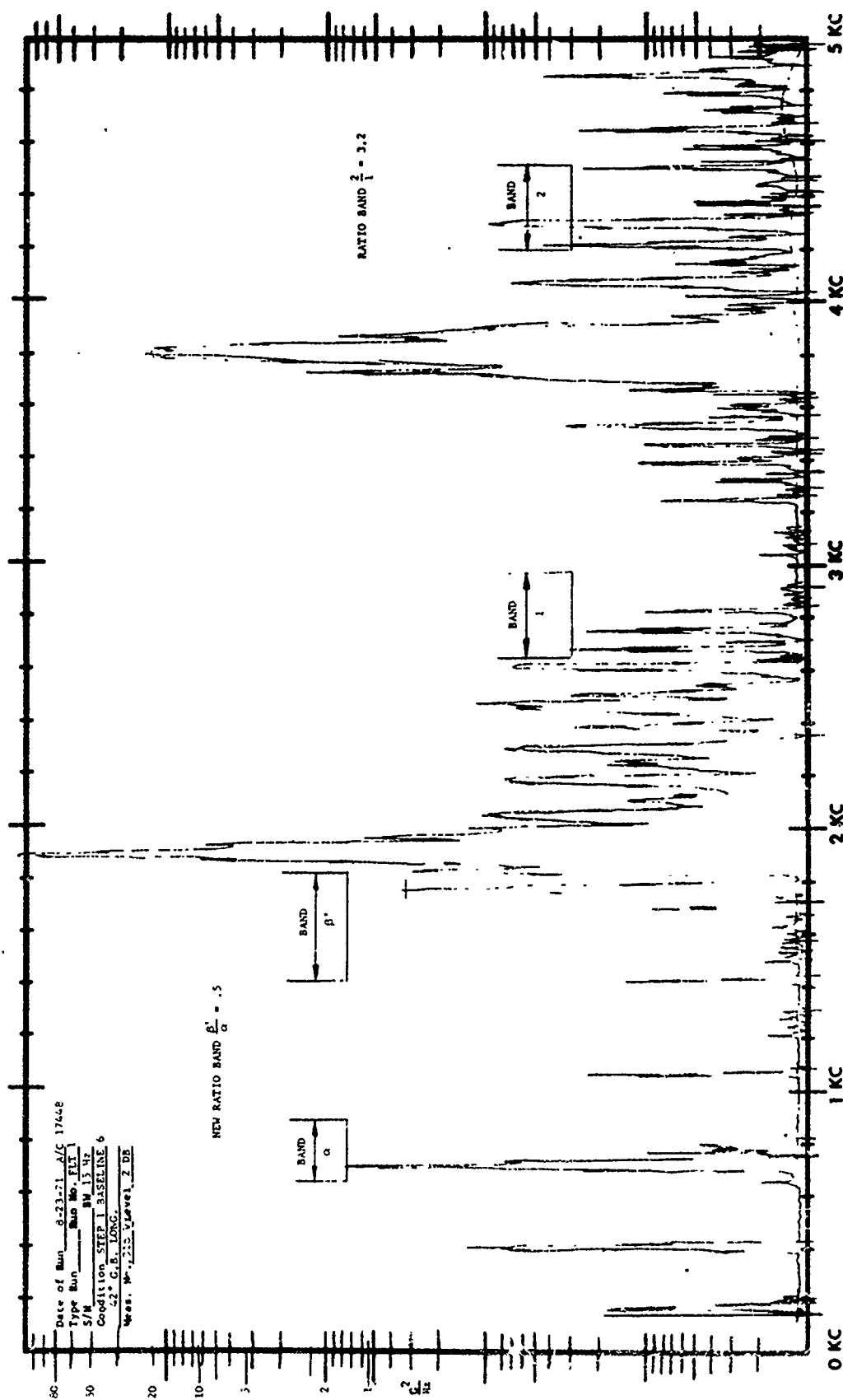


FIGURE 7-169 42° GEARBOX LONGITUDINAL, 8/23/71  
A/C 17448, STEP 1, BASELINE 6

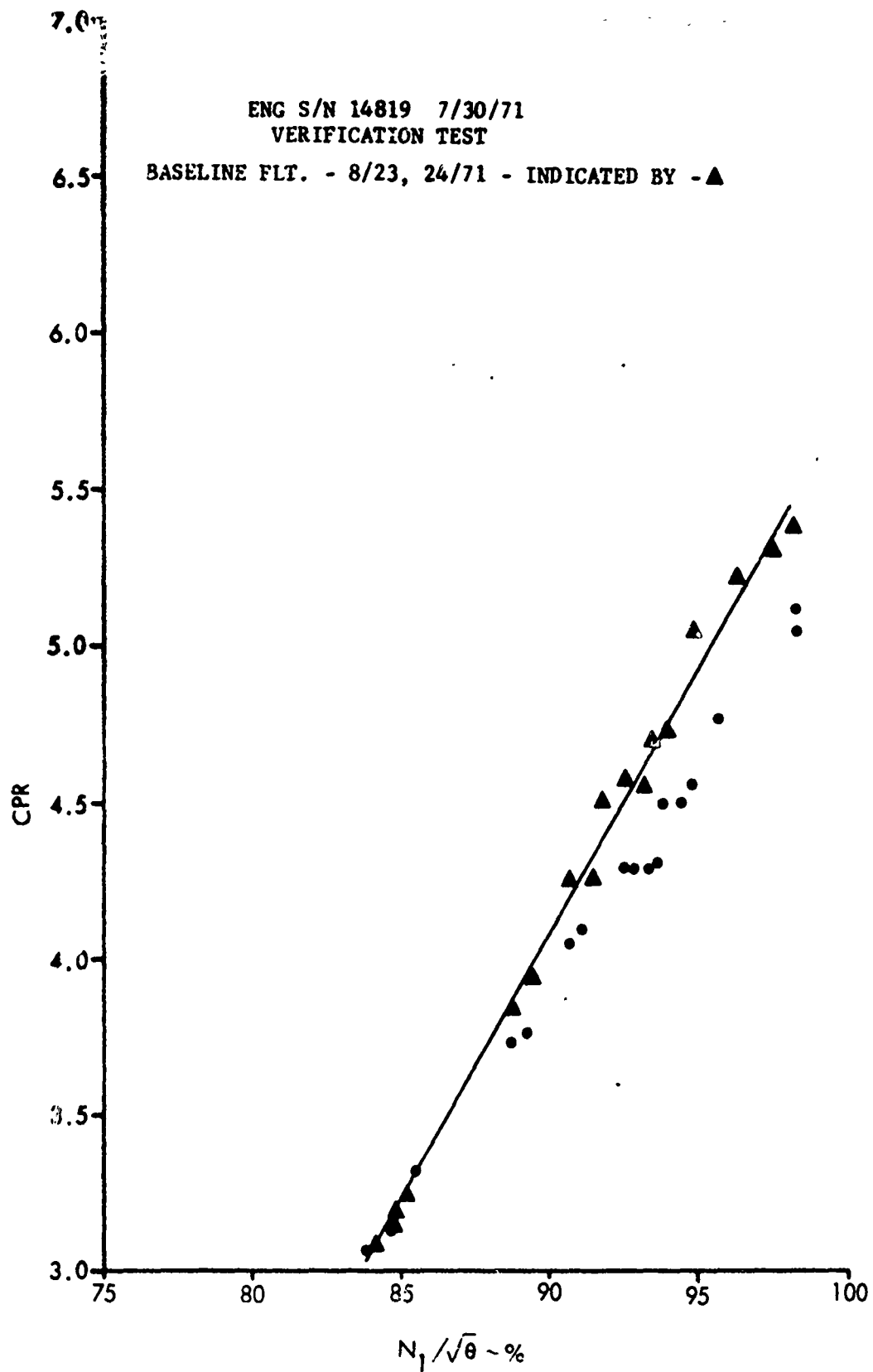


FIGURE 7-170 COMPRESSOR PRESSURE RATIO  
VS  
CORRECTED  $N_1$  SPEED

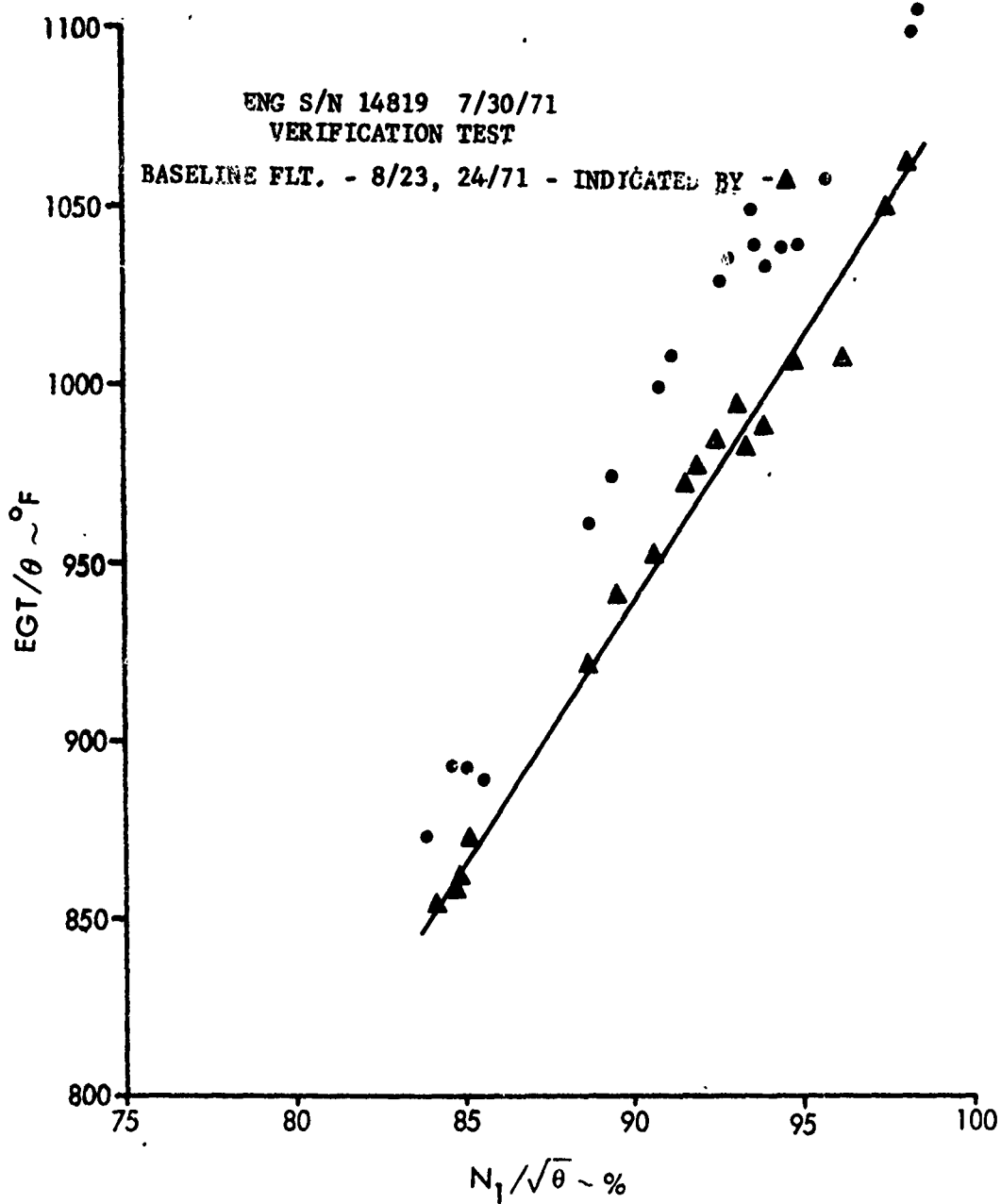


FIGURE 7-171 CORRECTED EXHAUST GAS TEMPERATURE  
VS  
CORRECTED  $N_1$  SPEED

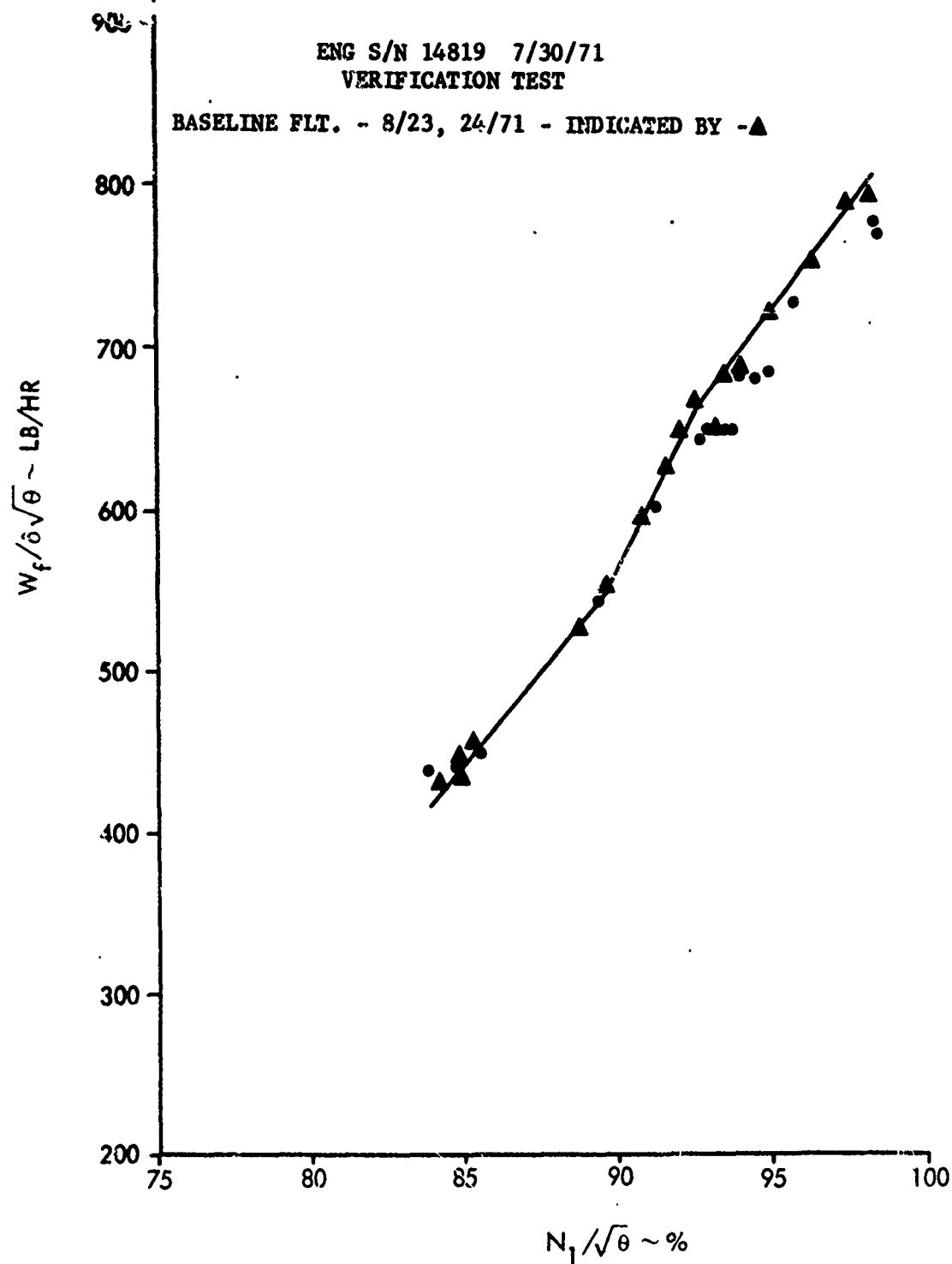


FIGURE 7-172 CORRECTED FUEL FLOW  
VS  
CORRECTED  $N_1$  SPEED

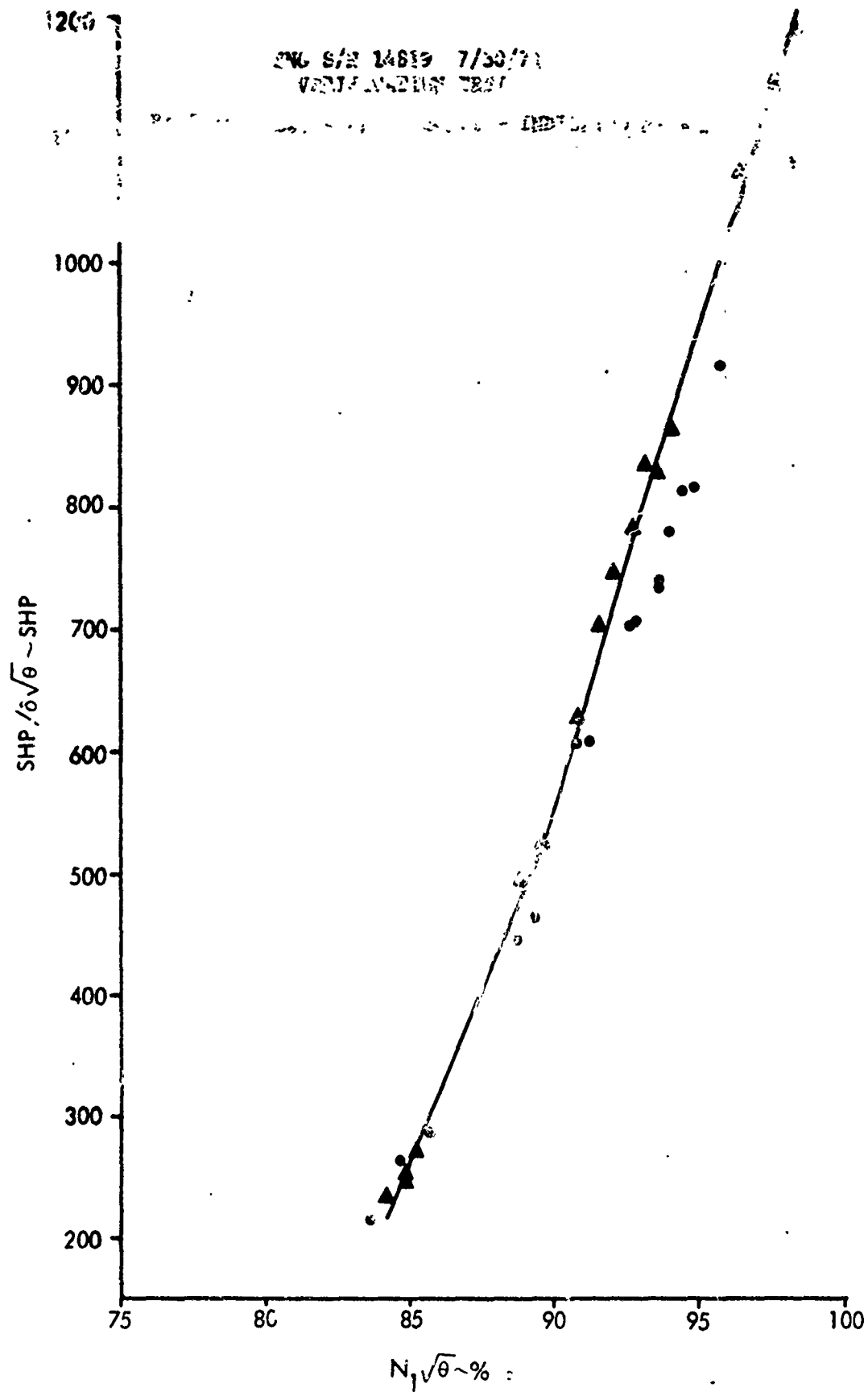


FIGURE 7-173 CORRECTED SHAFT HORSEPOWER  
VS  
CORRECTED  $N_1$  SPEED

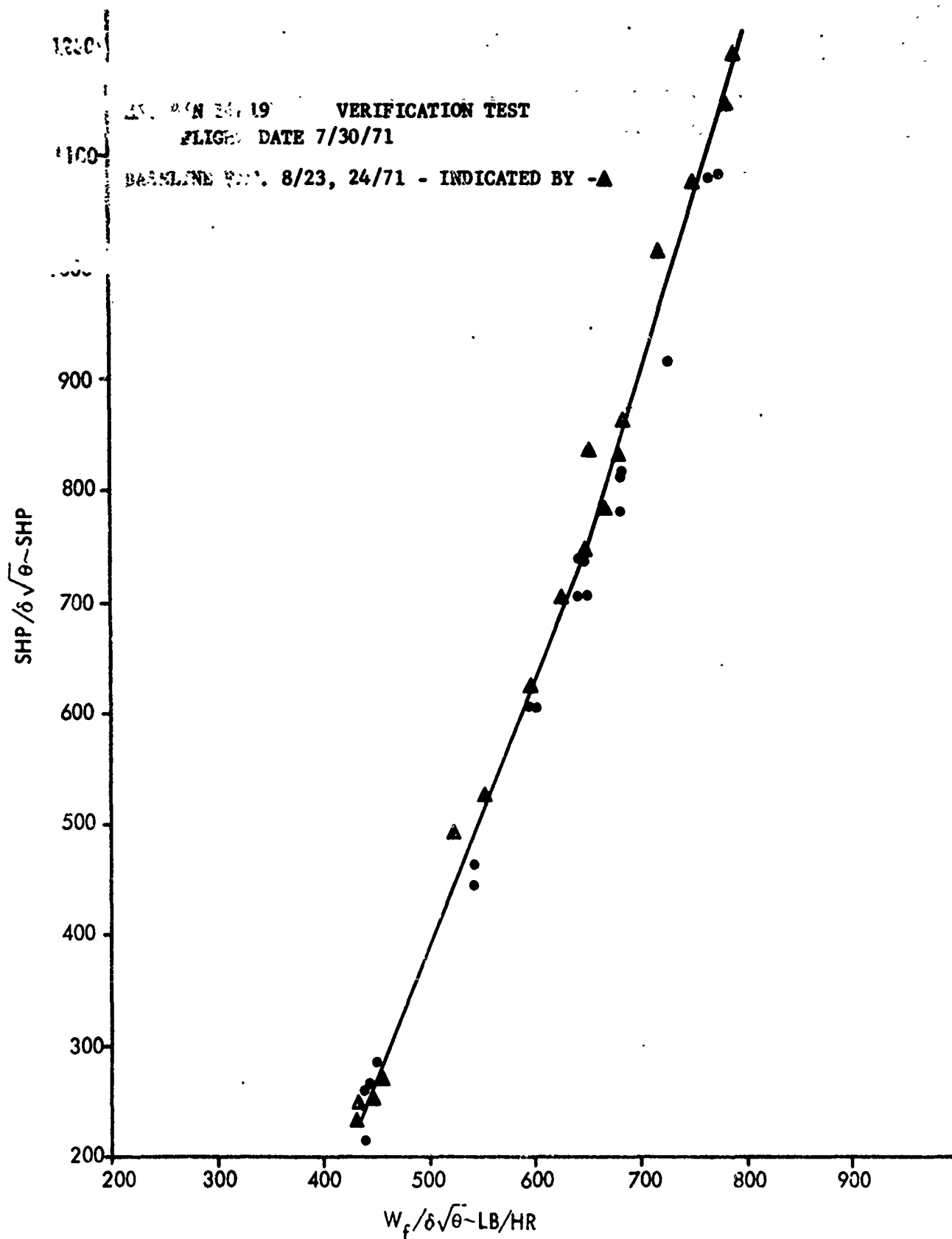


FIGURE 7-174 CORRECTED SHAFT HORSEPOWER  
 VS  
 CORRECTED FUEL FLOW

the following paragraphs. However, a summary chart has also been prepared for the gas flow analysis accomplished for the verification test engines and is shown as table 7.17. This presents on one form the significant deviations presented on the earlier detailed graphs.

#### Engine -

Figures 7-175 and 7-176 summarize the vibration ratios obtained for the engines tested during the verification program. An engine was considered faulty if band F/D was greater than 4.5. When a comparison is made between the engine's first flight and its baseline flight, a clear cut difference between good and bad is not always indicated. The lack of significant differences between verification and baseline was due to mechanical defects within the engine and not to a breakdown of the analysis criteria. Those engines which Northrop suspected of containing some (unplanned) defects were torn down and inspected and in almost all cases verified Northrop's conclusions as indicated by the results of the right-hand column.

In summary, the correct detection and identification of engine health by vibration and gas path analysis during verification was significant. Engines which were thought to be good have been identified as containing faults that were not detectable during test cell checkout and not discernible (except for the warped adapter plate) by the pilot.

For completeness, while not employed for verification test results, one additional band (G/F) was provided during phase E to permit even better fault isolation to be accomplished on the engine. This band is shown applied to verification data on figure 7-177 and is more fully discussed in Volume II.

#### 42° Gearbox -

During calibration of the accelerometers for the 42° gearbox, the lateral and longitudinal accelerometers became inadvertently interchanged. Before the problem was discovered, all the baseline flights had been completed. Since only the longitudinal accelerometer was normally recorded, useless lateral accelerometer data was recorded and the entire baseline was lost. Therefore, the original criteria used during the verification test program was based upon only one example of no defect and four examples of discrepancies.

TABLE 7.17 SUMMARY OF VERIFICATION TESTS, ENGINES

Engine S/N	Date of Flight	Discrepancy	CPR vs $N_1/\sqrt{\theta}$	EGT/θ vs $N_1/\sqrt{\theta}$	$W_p/\theta\sqrt{\theta}$ vs $N_1/\sqrt{\theta}$	SEP/θ/√θ vs $N_1/\sqrt{\theta}$	SEP/θ/√θ vs $W_p/\sqrt{\theta}$	SET NUMBER
16886	7-19-71	No. 2 Bearing	No Effect	Slightly Higher ( $<2\%$ )	No Effect	Slightly Lower ( $<2\%$ )	Slightly Lower ( $<2\%$ )	1
18301	7-19-71	No. 2 Bearing & $N_2$ Nozzles	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	No Effect	Slightly Higher ( $<2\%$ )	No Effect	2
20791	7-26-71	FOD & Turbine Unbalance	Slightly Higher ( $<2\%$ )	No Effect	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	Slightly Lower ( $<2\%$ )	3
18270	7-22/23-71	No. 1 & 2 Bearings	No Effect	Slightly Lower ( $<2\%$ )	No Effect	No Effect	No Effect	4
17376	7-2/3-71	$N_1$ Nozzles	No Effect	Slightly Lower ( $<2\%$ )	No Effect	No Effect	No Effect	5
14819	7-30-71	Compressor	Lower ( $>2\%$ , $<10\%$ )	Much Higher ( $>10\%$ )	Slightly Lower ( $<2\%$ )	Slightly Lower ( $<2\%$ )	No Effect	6

TABLE 7.17 SUMMARY OF VERIFICATION TESTS, ENGINES

Engine S/N	Date of Flight	Discrepancy	CPR vs $N_1/\sqrt{\theta}$	EOT/θ vs $N_1/\sqrt{\theta}$	$W_p/\delta\sqrt{\theta}$ vs $N_1/\sqrt{\theta}$	$SEP/\delta\sqrt{\theta}$ vs $N_1/\sqrt{\theta}$	$SEP/\delta\sqrt{\theta}$ vs $W_p/\sqrt{\theta}$	SET NUMBER
16886	7-19-71	No. 2 Bearing	No Effect	Slightly Higher ( $<2\%$ )	No Effect	Slightly Lower ( $<2\%$ )	Slightly Lower ( $<2\%$ )	1
18301	7-19-71	No. 2 Bearing & $N_2$ Nozzles	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	No Effect	Slightly Higher ( $<2\%$ )	No Effect	2
20791	7-26-71	FOD & Turbine Unbalance	Slightly Higher ( $<2\%$ )	No Effect	Slightly Higher ( $<2\%$ )	Slightly Higher ( $<2\%$ )	Slightly Lower ( $<2\%$ )	3
18270	7-22/23-71	No. 1 & 2 Bearings	No Effect	Slightly Lower ( $<2\%$ )	No Effect	No Effect	No Effect	4
17376	7-2/3-71	$N_1$ Nozzles	No Effect	Slightly Lower ( $<2\%$ )	No Effect	No Effect	No Effect	5
14819	7-30-71	Compressor	Lower $>2\%$ , $<10\%$	Much Higher ( $>10\%$ )	Slightly Lower ( $<2\%$ )	Slightly Lower ( $<2\%$ )	No Effect	6

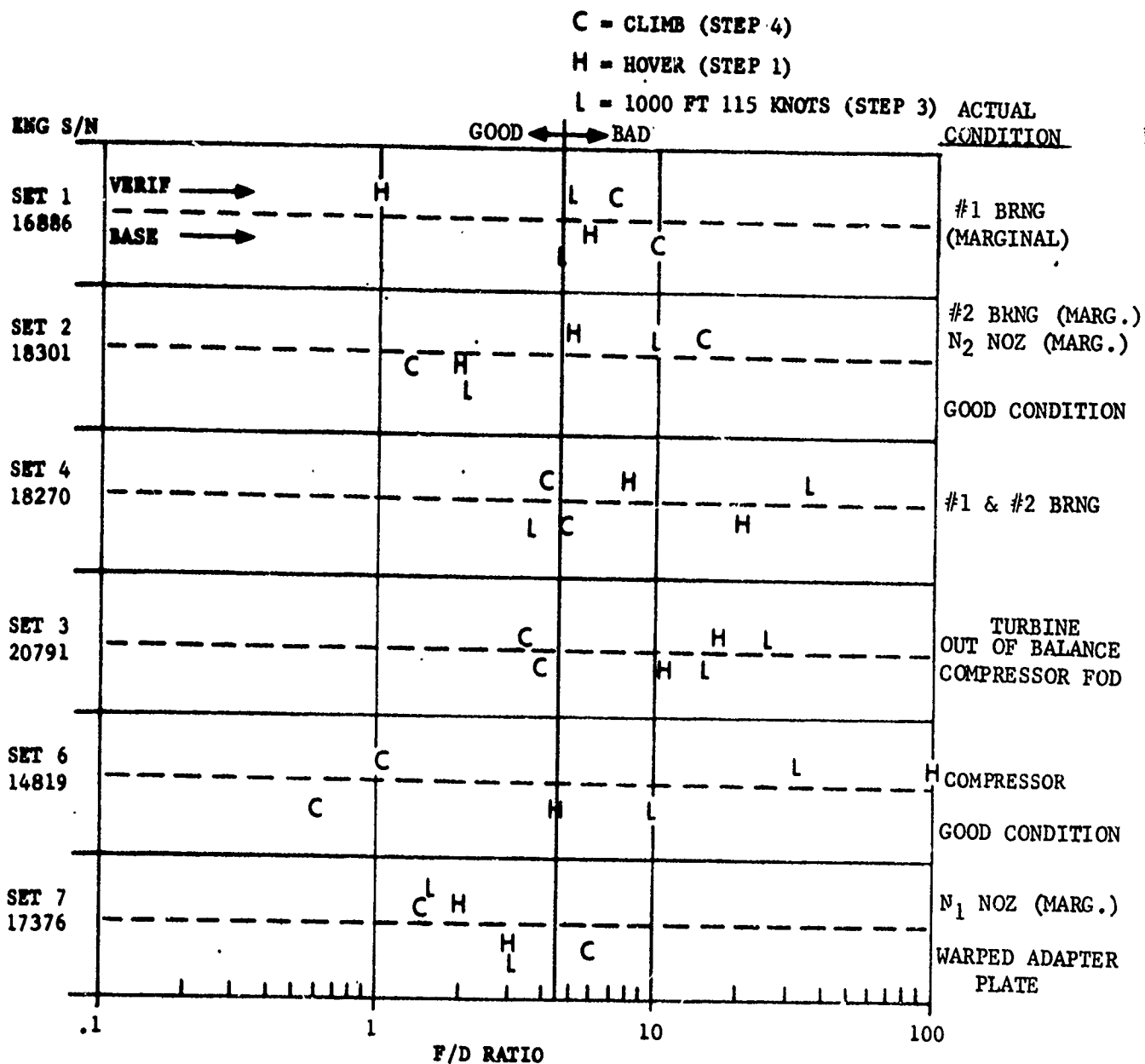


FIGURE 7-175 ENGINE F/D VIBRATION RATIO - VERIFICATION TESTS

C = CLIMB (STEP 4)  
H = HOVER (STEP 1)  
L = 1000 FT 115 KNOTS (STEP 3)

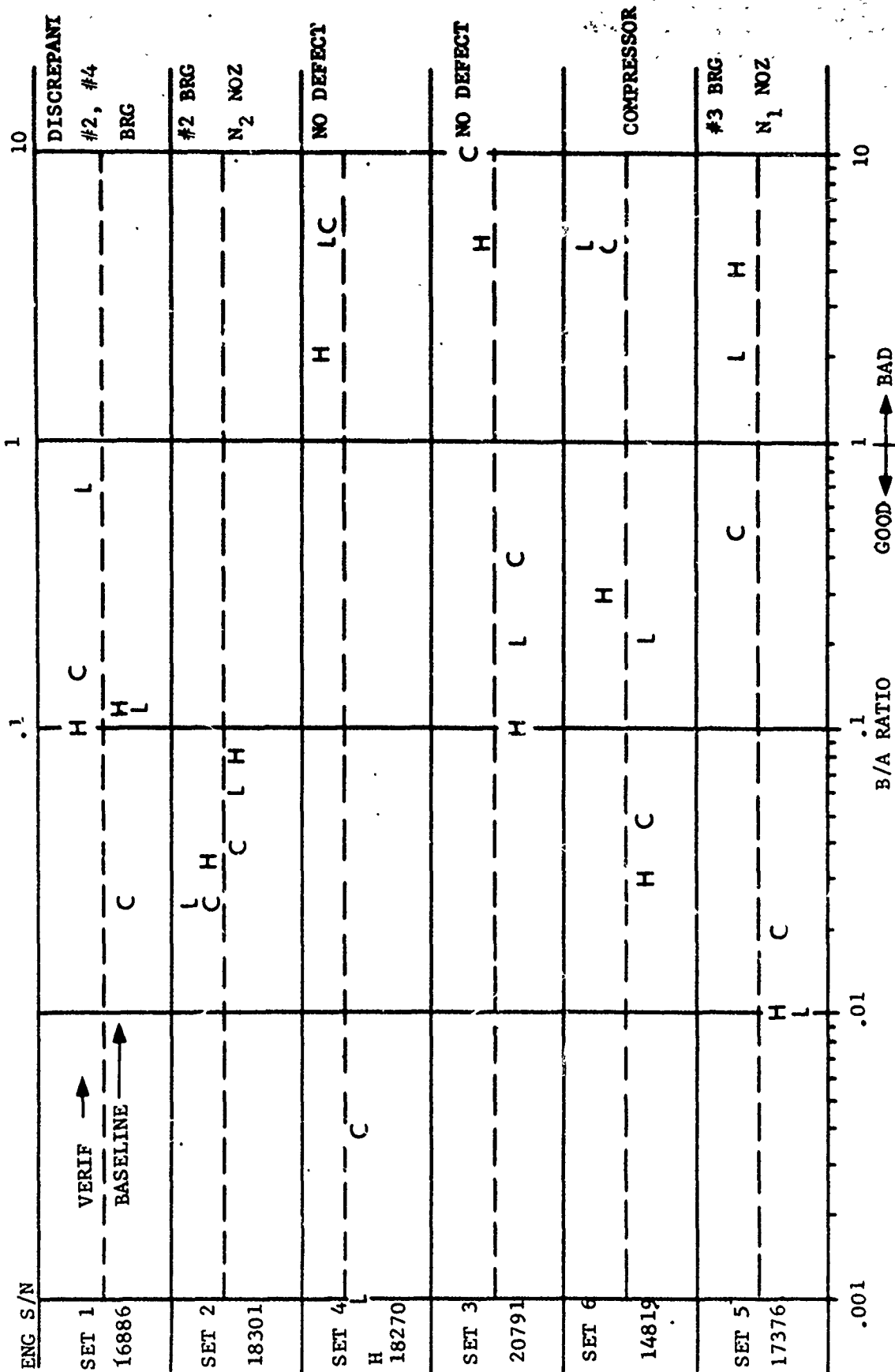


FIGURE 7-176 ENGINE B/A VIBRATION RATIO - VERIFICATION TESTS

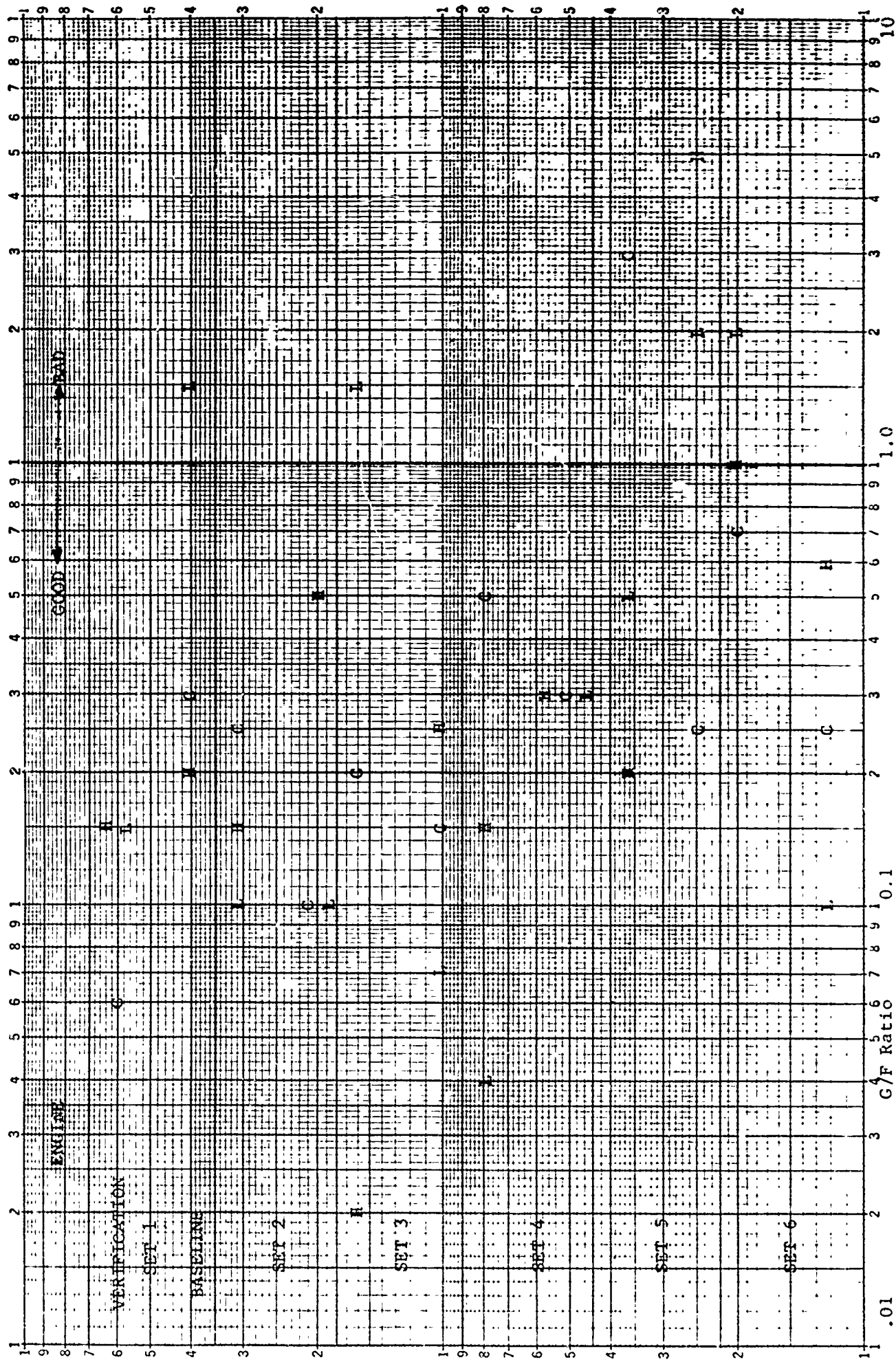


FIGURE 7-177 ENGINE RATIO ADDED FOR PHASE E

Even though the criteria was able to detect some of the discrepant implants, the performance was not optimized. Examination of the information collected during the verification, and subsequent baseline tests, indicated that a more sensitive criteria could be employed. Continued review and analysis of accumulated data resulted in a modified criteria.

The results of these criteria are shown in Figure 7-178. Threshold of failure is set at 1.0. The overall percentage of proper determinations concerning the mechanical condition of the 42° gearbox is quite high.

#### 90° Gearbox and Transmission -

To complete the presentation of summary data, the 90° gearbox and transmission data is shown as figures 7-179 and 7-180. These figures summarize the application of the ratio technique for the hover flight condition. The variation from one set of conditions to another is evidenced as well as the comparison of verification data to baseline data. These figures represent the latest application of the ratio technique incorporated in phase E applied to the verification data.

While the original criteria did correctly identify some component conditions, the nature of the previously available data with regard to actual mechanical condition was not defined until later in the program. Once this information was obtained, it was possible to optimize the criteria and substantially improve the diagnosis of component condition.

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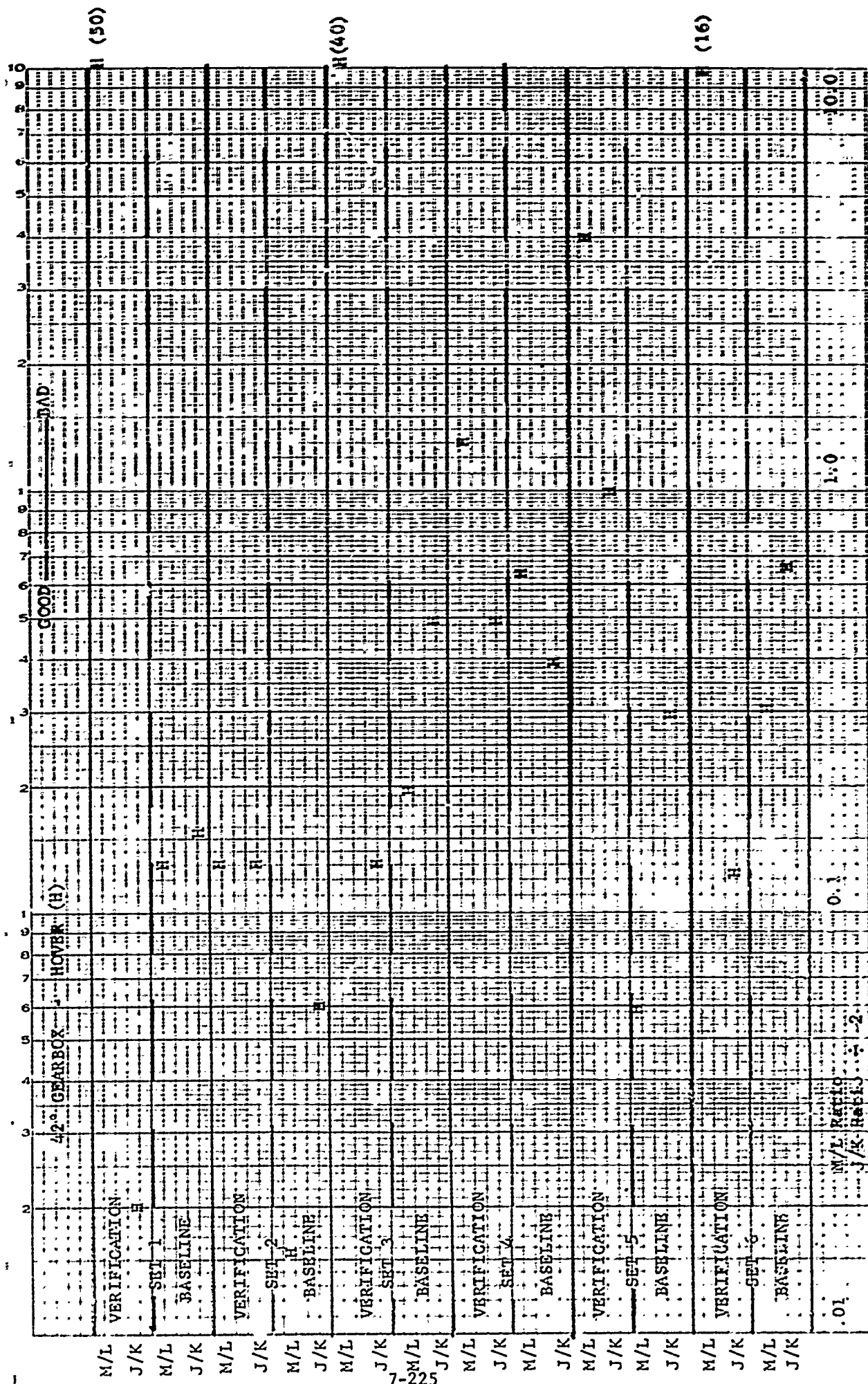


FIGURE 7-178 NEW 42° GEAR BOX VIBRATION RATIOS - VERIFICATION TESTS

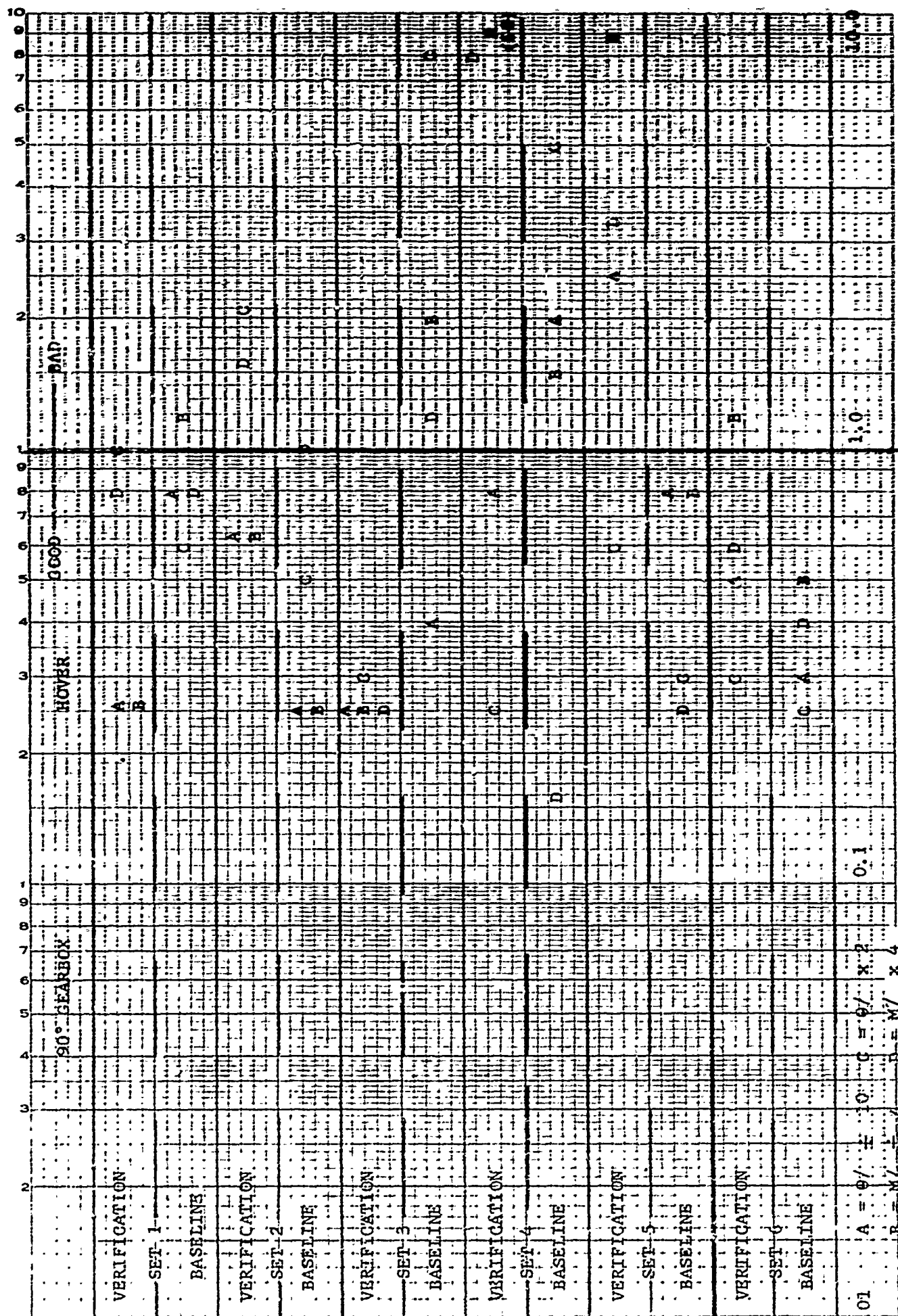


FIGURE 7-179 REVISED 90° GEARBOX VIBRATION CRITERIA

		GOOD										BAD																			
		2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	10	11	12										
VERIFICATION	SET 1																														
VERIFICATION	SET 2																														
VERIFICATION	SET 3																														
VERIFICATION	SET 4																														
VERIFICATION	SET 5																														
VERIFICATION	SET 6																														
0.01																															

FIGURE 7-180 REVISED TRANSMISSION VIBRATION CRITERIA

## **SECTION 8**

## 8.0 RESULTS AND CONCLUSIONS

This section presents the results and conclusions derived from the UH-1H test bed program.

### 8.1 DISCREPANT PARTS SELECTION

The impact of the degree of degradation of the parts selected as implants on the overall test bed results has been briefly addressed in previous sections of this report. In view of its importance, it merits additional comment.

#### 8.1.1 SELECTION PROCESS

The discrepant parts were selected by engineering personnel of the Aviation Systems Command collocated at ARADMAC. The criteria for individual parts selection was of necessity a compromise between the requirement for realism in the parts discrepancy and safety considerations both during the test cell runs and the flight tests.

It was desired to evaluate the degree of component degradation relative to parameter changes and thus determine levels of degradation versus detection capability. The levels of degradation ranged from only slightly discrepant to field replacement required.

##### 8.1.1.1 Engine Parts

The selection of internal engine parts was limited to compressors, nozzles, turbines and bearings. Compressors were selected with FOD and abrasion discrepancies comparable to the damage commonly discovered by Army mechanics in the field. The selection process for nozzles, turbines and bearings encompassed a range of degradation from slightly worn to 'bad' with a majority being marginal discrepancies. Nozzles and turbines in the main had minor cracks and evidence of erosion which did not significantly detract from engine performance. Engine bearings that were considered minimally discrepant were selected to a substantial degree on discoloration, minor pitting and limited spalling. Examples of these minor discrepancies are presented in Figure 8-1.

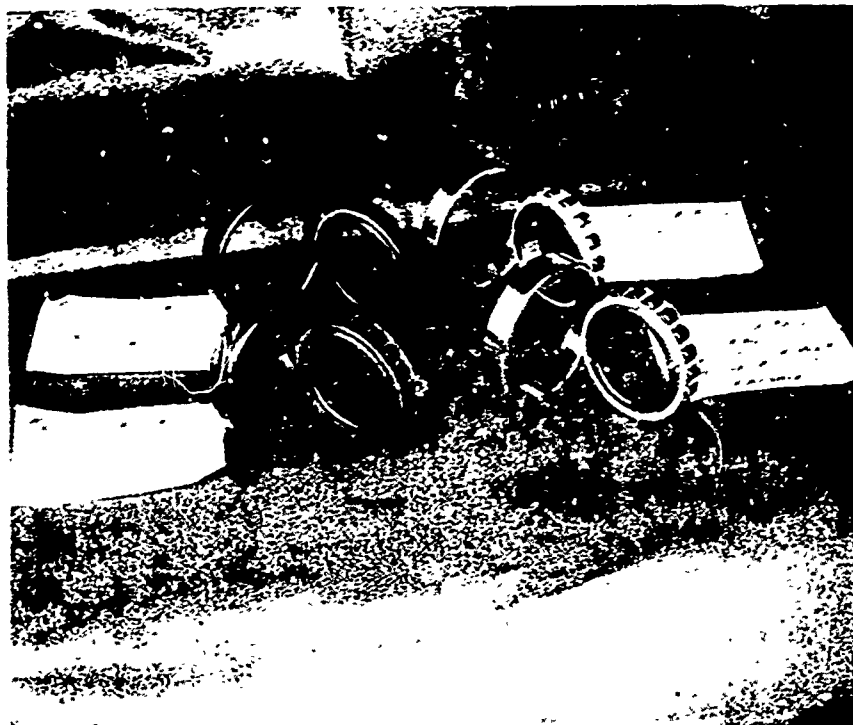
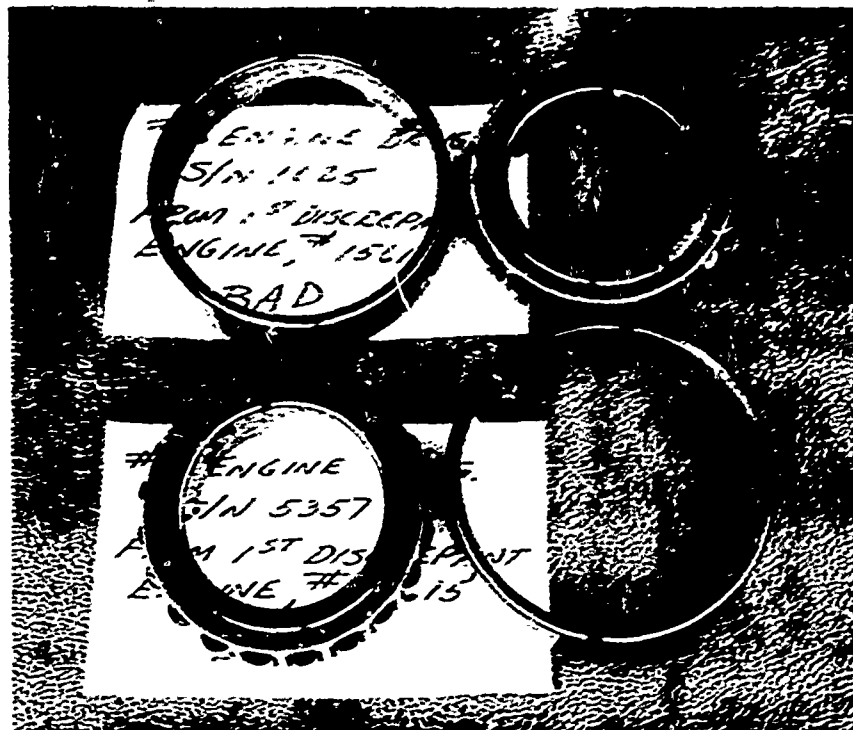


FIGURE 3-1 TYPICAL MINOR DISCREPANT BEARINGS

#### **8.1.1.2 Transmission Parts**

The selection of transmission parts encompassed a range from slightly worn to 'bad' with a majority being marginal. Bearing discrepancies were basically the same as for the engine. Gears had minor teeth wear, grooves, slight metal build up, and minor spalling; however, they were implanted only for the test cell runs.

#### **8.1.1.3 Gearbox Parts**

The comments concerning the engine and transmission bearing degree of degradation are also applicable to the gearbox parts.

### **8.1.2 TEST CELL RESULTS**

In discussing the degree of degradation of the discrepant parts, the point was made in Section 1 and bears repeating here, that only a small portion of all the discrepant parts that were run in the ARADMAC test cells using production test equipment exceeded test cell instrumentation limits. In other words, a number of components with implanted discrepant parts run through the test cells were serviceable based on the test cell run sheet criteria.

Figure 8-2 presents the overall nature of the discrepant parts in graphic form. This figure correlates parts condition to time. The test cell results of the discrepant part runs indicate the marginally discrepant parts exhibited overlapping characteristics (good) with overhauled components. The other designated points on the figure represent component failure, degradation detection, and removal action prior to failure. The significance of this illustration lies in the fact that the marginally discrepant parts used in the test bed program in most cases did not exhibit the full range of signature characteristics normally associated with discrepant parts.

### **8.1.3 CONCLUSIONS**

In conclusion, the results of the test bed program demonstrate that the MRS possesses the capability to detect helicopter malfunctions and of isolating faulty components. This capability was demonstrated using components with a very limited degree of degradation. Application of the MRS to the kinds of discrepant parts normally countered by units of the Army-in-the-field would result in correct diagnoses of discrepant parts, as well as permitting prognosis of remaining life in serviceable components.

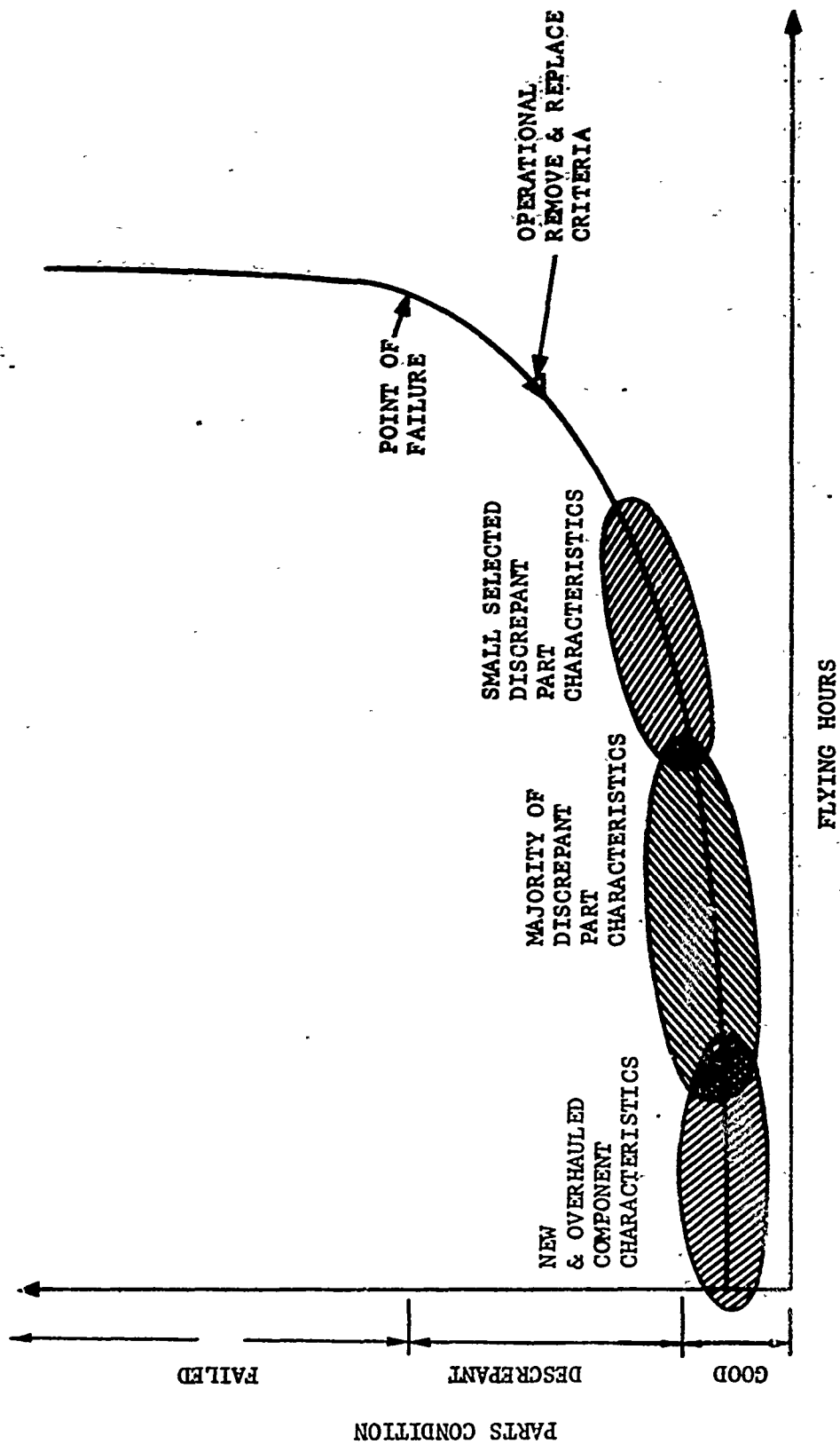


FIGURE 8-2 PARTS CONDITION VS FLYING HOURS

## 8.2 FAULT ISOLATION

One of the primary objectives of the test bed program was to validate the capability of the MRS to fault isolate components to the Line Replaceable Unit (LRU) and within the LRU level. As stated previously, the rationale for this objective is that the MRS must support the Department of the Army Logistics Offensive Program (LOP). Key segments of LOP are Maintenance Support Positive (MS+) and Direct Exchange (DX). MS+ envisages extensive usage of the maintenance functions of LRU removal and replacement in forward areas of a combat zone. Implementation of MS+ hinges on the continuous availability of serviceable LRU's at the Direct Support maintenance level on a DX basis. Typical maintenance actions required of the Army aviation mechanic in the field in implementing the LOP are as follows:

- a) Positive fault isolation of an aircraft maintenance problem to the LRU level.
- b) Removal of the discrepant LRU.
- c) Direct exchange of the discrepant LRU over the counter for a serviceable component.
- d) Installation of the serviceable LRU.
- e) Testing to validate the system operation.

The results of faulty LRU detection during the test bed were good. During the verification testing, faulty LRU's were correctly diagnosed a majority of the time. These results were achieved even though the majority of the implanted components were only marginally discrepant. The vibration monitoring mechanization is an excellent case in point in that a complex vibration analyzer was built on two circuit boards. The analyzer monitors vibration on four LRUs; the engine, transmission, 42 and 90 degree gearboxes. The test bed results show that in addition to fault isolating these components to the LRU level, it was possible to isolate some discrepant components within LRUs. Typical examples are engine compressors and  $N_1$  nozzles discussed in Section 7.0. An unplanned incident is also discussed in Section 8.6.1 where the MRS detected and reported that the #3 and #4 engine bearing package

was malfunctioning. This condition was caused by a leaking oil fitting. Projecting these results to a field environment where truly degraded bearings were overheating due to frictional losses, the same credible diagnoses and bearing fault isolation would be made and prognosis of the remaining time on a serviceable component would be possible. The point is that although LRU fault isolation was the prime test bed objective; selected internal LRU fault isolation was also achieved by the MRS.

### 8.3 EFFECT OF THE FLIGHT MODE

#### 8.3.1 FLIGHT PROFILE

A standard flight profile (see Figure 7-2) consisting of ten steps, including hovering in and out of ground effect, climbs and descents at different airspeeds, and straight and level flight at varying airspeeds was used for aircraft which were flown with discrepant part implants. The flight profile duplicated a majority of the requirements for Army aircraft test flights as specified in DA Technical Bulletin 55-1500-311-25. This approach provided realism to the conduct of the test bed program. The aircraft and the MRS were used much as it will be by Army aviation units in the field. In addition, it provided a uniform control for evaluating the effect of various flight conditions on LRU performance.

#### 8.3.2 ENGINE GAS FLOW PERFORMANCE

The extensive study of engine gas flow performance accomplished throughout the flight program conclusively showed that the measurement of engine performance deterioration is a direct function of increasing power expended by the engine. In addition, the detectable performance degradation only starts manifesting itself at a power setting appreciably above Flight Idle. As a relevant example, take the case of engine 14819 with severe compressor FOD. Specifically refer to Figure 8-3 which shows the relationships of compressor pressure ratio (CPR) to  $N_1$  speed where  $N_1$  speed can be viewed as a measure of engine power. This figure clearly illustrates that the compressor section was degraded (low pressure) during verification tests (dot symbols) upon comparison with the baseline flight (triangle symbols). Notice that the verification and

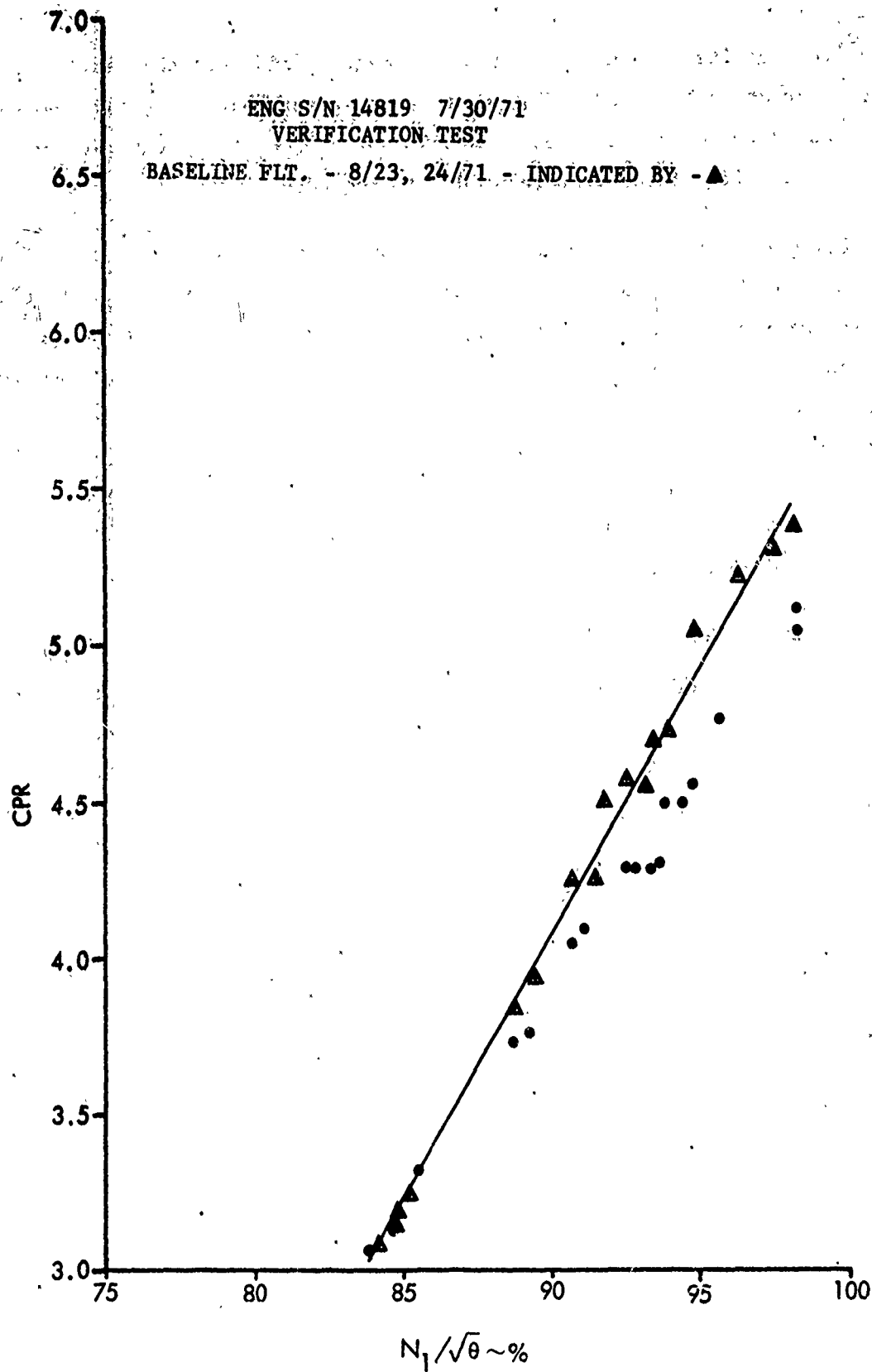


FIGURE 8-3. COMPRESSOR PRESSURE RATIO  
VS  
CORRECTED  $N_1$  SPEED

baseline results converge around 85 percent  $N_1$  and that the results diverge with increasing  $N_1$  speed. This observation means that the badly degraded compressor would not be detectable below 85 percent  $N_1$  by gas path analysis. Note that Flight Idle (72 percent  $N_1$ ) is included.

Using the preceding discussion as a basis, two conclusions can safely be drawn. One is that the higher the engine power level, the more reliable the engine health diagnosis. Secondly, it must be recognized that the FOD compressor used as an example represents a severe situation of engine performance deterioration. Practically speaking, a reliable diagnostic system should be able to detect a lower level of performance degradation. Therefore, it must be concluded that the power setting where engine performance begins to degrade is not 85 percent but higher.  $N_1$  values at least greater than 90 percent are recommended which in itself dictates an airborne condition.

#### 8.3.3 VIBRATION MONITORING

Vibration results accumulated during verification tests and subsequent baseline tests show no correlation of flight mode to the Vibration System Analyzer (VSA) outputs. Referring to the VSA ratio values obtained from the engines and 42 degree gearboxes in Figures 7-175 through 7-178, the three flight modes shown, hover (H), climb (C), and level flight (L), do not occur in a definite order on a specific flight. That is, climb is not always the highest value nor is hover the lowest. Therefore, it is observed that the effect of the three flight modes is completely random. Based on this evidence, it can be concluded that neither of the three flight modes, hover, climb, and level flight is a better condition to monitor vibration. Due to the random distribution, all three flight modes are equally likely to be successful.

#### 8.3.4 MISCELLANEOUS

In addition to the factors previously described which require continuous monitoring and high power settings in order to positively fault isolate discrepant parts, the following considerations which require the aircraft to be flown are furnished. These maintenance problems are recurring in nature and are regularly resolved by aviation units in the field.

#### 8.3.4.1 Main Rotor 1:1 Vertical Vibrations

Main rotor 1:1 vertical vibrations are caused simply by one blade developing more lift at a given point than the other blade develops at the same point. This vibration is airspeed sensitive. Corrective action includes an on the ground low and high speed rotor check with a tracking flag to bring both blades into the same tip path plane. The next step is to fly the aircraft and determine the airspeed value at which the vertical becomes evident. Evidence of the vertical vibration before 60 knots airspeed can normally be corrected by adjusting the pitch change tubes. Verticals occurring after 60 knots airspeed are corrected by trim tab adjustments.

#### 8.3.4.2 Power Check and Trim Adjustment Fuel Control

Another maintenance function that is constantly being accomplished by units in the field is adjustment of the fuel control. This function requires that the aircraft be flown. The procedure is to take off and climb at 6600 nII, airspeed 70 to 90 knots, pulling maximum torque (not exceeding 50 psi). This flight attitude is maintained until nII decays to 6400 rpm. The altitude at which this occurs is noted and becomes the test altitude. A descent of approximately 500 feet is then accomplished and the procedure repeated. At this point the torque pressure and nI speed are recorded. These data are used upon landing in conjunction with the UH-1H power adjustment chart to determine if fuel control adjustments are required.

#### 8.3.5 CONCLUSIONS

The conditions described above are typical of those faced continually by aviation units in the field. The MRS possesses the capability, through continuous monitoring, of reporting the status of the major components. An airborne diagnostic system is the only means of reliably detecting malfunctions in the areas described.

#### 8.4 VIBRATION MONITORING

Hardware mechanization of the MRS vibration monitoring system was developed from a thorough study of engine, transmission, and gearbox test cell results. As a subsection within the MRS, it is referred to as the Vibration Analyzer System (VSA). The VSA monitors vibration energy emitted by the engine and power train units in a unique manner. The concept is simply that the ratio

of the vibration energy in two specific frequency bands is measured. While mechanization of the concept was a challenging design effort, it was accomplished within the scope of two circuit cards. Separate ratios are calculated for engines, transmissions, 42 degree gearboxes, and 90 degree gearboxes. Advantages of the ratio method over previously investigated techniques are that it is independent of absolute accelerometer calibration. In addition, it tends to normalize the effects of power settings and can be applied universally to specific components without the necessity for comparing results with serial numbers.

Vibration proved to be the most useful diagnostic indicator during this program due to the type of discrepant implants used. In addition, the sensitivity of the VSA made it possible to detect small performance degradations from the degraded parts selected for the test bed program. Results recorded during verification testing indicated that the majority of the diagnosis were correct. This represents substantial evidence of the success of vibration monitoring technique. Specific results are as follows:

- a) Nine of the twelve 42 degree gearboxes conditions and ten of twelve engine conditions monitored during verification and baseline were diagnosed correctly. This achievement becomes even more significant when it is realized that four of the twelve engines contained unplanned discrepancies which were unknown until validated during subsequent tear down inspections.
- b) Excessive 90° gearbox vibration was detected on the flight of May 15, 1971 (refer to Section 8.6.2). Investigation proved that the vibration system had correctly diagnosed a problem. In this instance, the 90° gearbox was loosely mounted. This incident is significant since it illustrates the detection of improper component conditions including improper installation. Several other examples of detection of unplanned implants are discussed throughout this report.

In conclusion, it can be stated that a practical airborne vibration monitoring system was mechanized and successfully demonstrated.

## 8.5 ENGINE GAS FLOW MONITORING

The calculator is an airborne hardware mechanization of engine health indicators based on a standard specification engine. Selected engine parameters, exhaust gas temperature, compressor pressure ratio, and fuel flow are normalized against  $N_1$ , air temperature, and air pressure conditions. The calculator outputs are mechanized to be constants within the linear range of selected parameters; hence, deviations are interpreted as changes in normal engine performance.

Viewing the overall results, the calculator realistically reflects the gross behavior of the engine parameters when compared to the engine gas flow analysis results. In the case of degraded compressors, where gas flow analysis showed marked degradations in CPR and EGT, calculator outputs showed correspondingly large changes.

Gas flow analysis accomplished in the test bed program utilized MRS engine parameter data to determine dynamic engine performance. Results of the analysis supported and verified the performance of the engine calculator and effectively demonstrated detectable deviations from normal behavior produced by implanted discrepant parts. Twenty-one parts were implanted during flight test efforts. Five of these parts showed detectable degradations in gas flow performance and are briefly described in the following paragraphs.

- a) Three degraded compressors installed in engine S/N 15615, S/N 18993, and S/N 14819 showed substantial deterioration in compressor pressure ratio and increased EGT. In addition to these performance indicators, a loss in engine shaft horsepower was observed on engines S/N 18993 and S/N 14819 which also indicated compressor damage.
- b) A defective power turbine installed in engine S/N 20727 was detected by indication of higher EGT compared to the baseline values.
- c) A defective N2 nozzle installed in engine S/N 18993 was indicated by higher EGT and increased shaft horsepower. This is characteristic of an increased N2 nozzle area which increases the engine mass flow. Increase in engine fuel flow was also observed.

Gas flow analysis of the trend aircraft 66-17138 engine showed no discernable change in performance during the 236 hours accumulated during the program. Engine S/N 16382 used on aircraft 66-17138 had been overhauled just prior to being assigned to the test bed program. No gas path problems occurred with the engine during the 236 flying hours of the program; therefore, no significant malfunction data was obtained.

Two approaches were taken in regard to engine health evaluation throughout the course of the program. The MRS hardware was mechanized to automatically apply a universal threshold limit during computations of engine health. The technique worked well for engine discrepancies that were representative of problems requiring immediate action in the field. The other approach applied ground analysis techniques to verify airborne computations and to determine whether threshold limits peculiar to each engine serial number based on baseline data produced results more applicable to trending techniques. The results of this approach supported the correctness of the airborne computations and resulting diagnosis. It was also found that to permit trends to be detected in engines that would permit significantly earlier indications of engine problems to be obtained, the serial number approach produced better results. For the majority of the discrepant parts employed throughout the course of the program, the latter approach is recommended.

In general, it has been demonstrated that airborne mechanizations of engine performance equations can be employed effectively to monitor and evaluate engine health and to isolate the fault to specific component problem areas.

#### 8.6 UNSCHEDULED INCIDENTS

During the course of the flight test program, several abnormal conditions were detected by MRS monitoring which were not part of the programmed discrepant implantes. The ability to detect these conditions substantiates the versatility of overall MRS approach.

#### 8.6.1 #3 AND #4 BEARING OVERTEMPERATURE

An output from the MRS was recovered (from the maintenance data recorder) which indicated that the #3 and #4 package was discrepant. The differential temperature had exceeded the maximum allowable value (122°C).

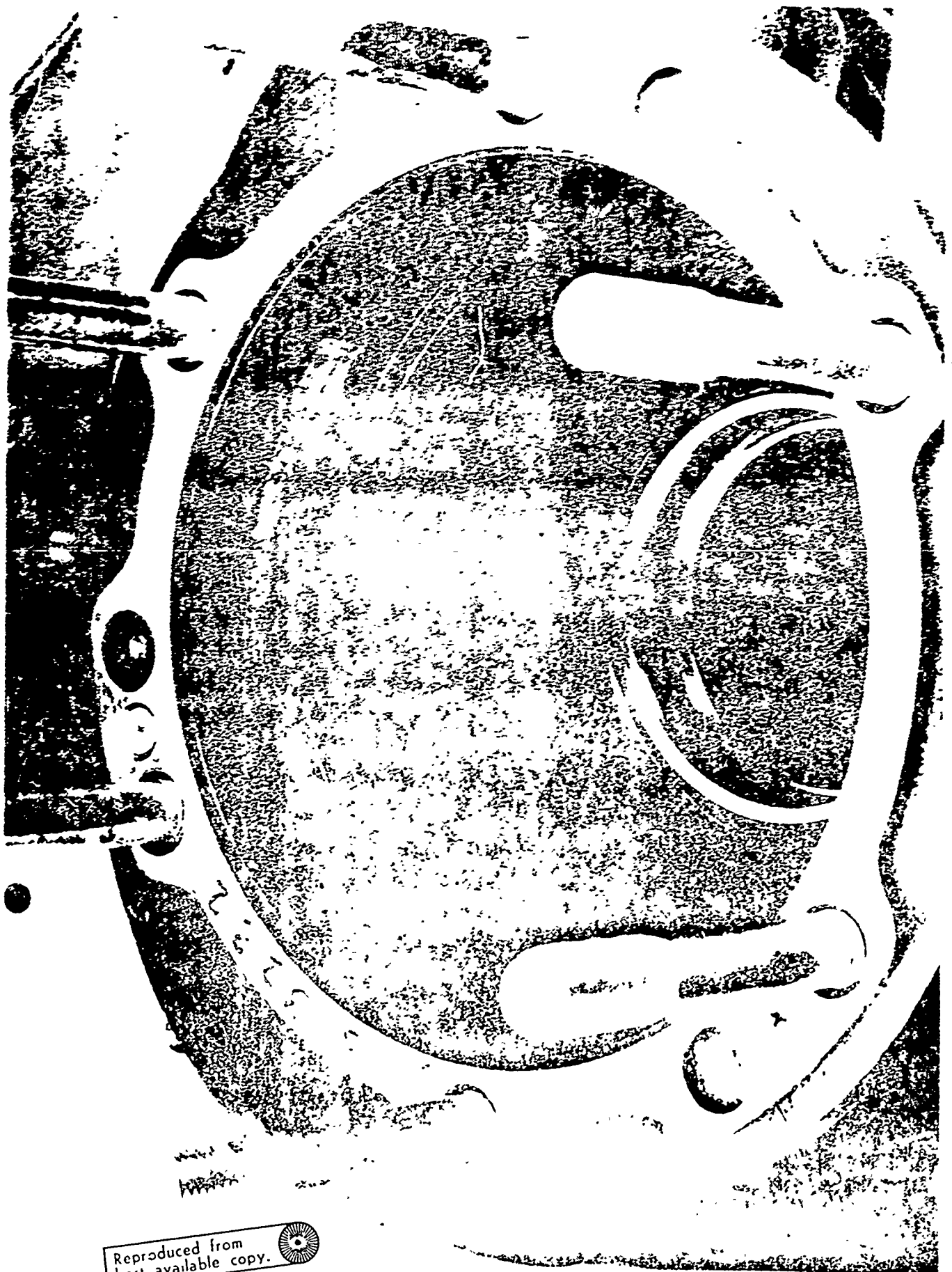
Subsequent disassembly of the bearing housing and assembly revealed no noticeable change in the condition of the #3 bearing, but a leak at the bearing housing scavenge port fitting was evident (see Figure 7-102, Section 7.7.3). The opinion of knowledgeable ARADMAC personnel was that the leaking fitting, which is surrounded by high temperature air, caused the scavenged oil temperature to rise. The rise in temperature of the scavenge line, in turn, caused the excessive differential temperature. The ability to detect this condition demonstrates that a damaged or deteriorating bearing seal could also be detected because the local (scavenge) oil temperature would be directly effected.

#### 8.6.2 90° GEARBOX IMPROPERLY INSTALLED

While obtaining baseline data for the set of no defect parts flown on May 12, 1971 (aircraft 67-17448), excessive vibration of the 90° gearbox was detected. Because the vibration levels were higher than previously experienced, an inspection of the gearbox was requested. Examination of the gearbox (see Figure 8-4) revealed that the input bearing had been rotating because the gearbox retaining nuts had not been correctly torqued during installation. Early detection of this condition by vibration monitoring demonstrates the ability of the MRS system to correctly diagnose a condition which, in normal Army field operations, may have progressed to a safety of flight condition before other physical evidence indicated a problem.

#### 8.6.3 CHIPS DETECTION

Chips indications were detected by the MRS on two of the baseline flights of LRU's used for verification testing. The flight of September 3, 1971 had a 90° gearbox chips indication and engine chips were detected on the August 24, 1971 flight. Both of the indications were verified by the aircraft cockpit light indicators and inspection of the chip detectors verified the presence of chips.



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#### 8.6.4 WARPED ENGINE DRIVE ADAPTER PLATE (REFERENCE SECTION 7.9)

During the baseline flight of the fifth set of verification LRU's on August 2, 1971, excessive vibration was detected by both transmission and engine monitoring. Also, during this same flight, the pilot had been monitoring an unusual noise in the engine compartment, and became concerned enough to land the aircraft for a visual inspection. Nothing unusual was discovered. Based upon previous test bed experience, the engine was diagnosed as discrepant even though it contained no specially implanted discrepant parts. The transmission was diagnosed as having higher vibration than during previous flights and was considered to be in a marginal condition.

Subsequent inspection of the engine hot section and the basic engine disclosed nothing which would account for the unusual noise detected by the pilot or the vibration problem.

Another inspection of the drive system, after the engine was reinstalled and test flown, revealed a warped engine drive shaft adapter. In addition, further investigation of the signature of this discrepant has revealed that a new ratio added to the present engine vibration monitoring scheme will definitely detect this type of problem. The criteria used for detection has shown the drive shaft adapter vibration at the shaft frequency to be nearly fifty times greater than the no defect condition during verification (see Figure 7-166 and 7-167). Other drive shaft assembly or installation problems would also be detected by this criteria. Maintenance data indicates the drive shaft assembly accounts for approximately 65 man-hours per 1000 flight hours, a significant number.

#### 8.6.5 OTHER

Numerous other unplanned incidents have been reported as part of the verification test results and will not be further discussed here.

## 8.7 OVERALL RESULTS

The emphasis and one of the most important results of the program is the diagnosis accomplished for a special test conducted at the end of phase D. This test has been previously discussed in section 7.0 in great detail and is known as verification testing. The test conduct consisted of six different samples of four basic components installed in a UH-1 and flown in a condition completely unknown to the contractor but are established by Army specialists. This resulted in a total sample of 24 items for verification that were in unidentified conditions that varied from good components to field replacement required. The majority of parts, however, contained only minor discrepant. Immediately subsequent to accomplishing the flights with these 24 major components, a statement regarding component health based on the hardware mechanizations and analytical findings from the data collected during the flights was provided.

Following this segment of flights, a series of baseline flights were performed. These baseline flights were accomplished with the same 24 components, only this time it was stated that they were in good condition. The purpose of these flights was to accumulate more baseline data on component characteristics beyond the few samples that had been obtained up to that point in time.

For the sake of consistency and to verify the applicability of previously established diagnostic decision criteria, the data was obtained and handled in the same manner as during the previous tests. Based on the stated component condition of good (baseline) parts, a similar determination was not only expected but an evaluation of the data could expect to be biased in verifying this condition since this status was known. The results, however, did not verify the original assumption that all parts were good. For example, as illustrated in table 7.13, it was determined that four of six allegedly good engines were in a discrepant condition. This diagnosis was verified by subsequent teardown analysis. Thus, the contractors were not only tested in the face of unknown component conditions, but also in the face of incorrectly defined conditions.

The results of both segments of these tests are shown on tables 8.1 and 8.2 . The data represents the number of correct diagnostic decisions per the number of samples available. The column entitled "Original Criteria" illustrates the ratio of correct decisions per sample size for criteria that was developed for a few selected flights of discrepant components prior to the initiation of the verification tests. Subsequent to the completion of the verification and baseline tests which, in themselves, added 12 new data points for each component, the diagnostic criteria was upgraded to reflect the full knowledge of the collected data. The results of applying this criteria, referred to as the "Revised Criteria" column, are also shown on the tables. Since the data base had been considerably expanded, the improved results are not unexpected.

When the components and discrepant parts were re-examined at the end of these tests, they were defined by Army analysis as good, marginal or discrepant. The diagnosis provided by the contractor also employed these three categories. Since it has been argued that marginal could be interpreted as marginal but still good as well as marginal but discrepant, the results of the tests are shown both ways. The only unusual effect this change in interpretation has is in viewing the results of the various transmissions flown. With marginal defined faulty, only 5 out of 12 components were correctly identified using the original criteria, and 11 out of 12 were correctly identified using the revised criteria. If marginal is defined as good, ten of twelve transmissions are correctly identified with the original criteria and all twelve are correctly diagnosed using the revised criteria.

An examination of total results illustrates that, in general, two-thirds (66%) of all components were correctly diagnosed using the original criteria, and when the improved criteria is applied, 86% of the components were correctly diagnosed.

TABLE 8.1

## SUMMARY OF PROGRAM RESULTS

(MARGINAL DEFINED AS FAULTY)

COMPONENT	VERIFICATION		BASELINE		TOTAL	
	ORIGINAL CRITERIA	REVISED CRITERIA	ORIGINAL CRITERIA	REVISED CRITERIA	ORIGINAL CRITERIA	REVISED CRITERIA
ENGINE	6/6	N/A	5/6	N/A	11/12	N/A
TRANSMISSION	4/6	5/6	1/6	6/6	5/12	11/12
42° GEAR BOX	4/6	6/6	5/6	5/6	9/12	11/12
90° GEAR BOX	1/6	5/6	3/6	4/6	4/12	9/12
TOTAL	15/24	22/24	12/24	20/24	29/48	42/48
	60	92	59	84	61	88

TABLE 8.2  
SUMMARY OF PROGRAM RESULTS  
(MARGINAL DEFINED AS GOOD)

COMPONENT	VERIFICATION		BASELINE		TOTAL	
	ORIGINAL CRITERIA	REVISED CRITERIA	ORIGINAL CRITERIA	REVISED CRITERIA	ORIGINAL CRITERIA	REVISED CRITERIA
ENGINE	5/6	N/A	5/6	N/A	10/12	N/A
TRANSMISSION	5/6	6/6	5/6	6/6	10/12	12/12
42° GEAR BOX	3/6	4/6	4/6	6/6	7/12	10/12
90° GEAR BOX	3/6	4/6	4/6	4/6	7/12	8/12
TOTAL	16/24	19/24	18/24	21/24	34/48	40/48
	67	80	75	88	71	84